DESIGN SOLUTIONS FOR GREEN WALLS IN INTERIOR SPACES

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ABBREVIATIONS

VOCs: Volatile organic compounds are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects

NOx: Is shorthand for nitric oxide (NO) and nitrogen dioxide (NO2), the nitrogen oxides that are most relevant for air pollution. These gases contribute to the formation of smog and acid rain, as well as affecting tropospheric ozone.

O3: Ozone is a highly reactive gas composed of three oxygen atoms. It is both a natural and a man-made product that occurs in the Earth's upper atmosphere ozone molecule (the stratosphere) and lower atmosphere (the troposphere).

UHI: An urban heat island, is a metropolitan area that's a lot warmer than the rural areas surrounding it. Heat is created by energy from all the people, cars, buses, and trains in big cities.

WSUD: Water-sensitive urban design is a land planning and engineering design approach which integrates the urban water cycle, including stormwater, groundwater, and wastewater management and water supply, into urban design to minimise environmental degradation and improve aesthetic and recreational appeal.

IAQ: Indoor Air Quality refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.

HVAC: stands for heating, ventilation, and air conditioning. It refers to the systems that regulate and move heated and cooled air throughout residential and commercial buildings, from homes to offices to indoor stadiums.

LEED: Leadership in Energy and Environmental Design is the world's most widely used green building rating system. LEED certification provides a framework for healthy, highly efficient, and cost-saving green buildings, which offer environmental, social and governance benefits. LEED certification is a globally recognized symbol of sustainability achievement, and it is backed by an entire industry of committed organizations and individuals paving the way for market transformation.

BMU: A building maintenance unit is an automatic, remote-controlled, or mechanical device, usually suspended from the roof, which moves systematically over some surface of a structure while carrying human window washers or mechanical robots to maintain or clean the covered surfaces.

LCA: Life-cycle assessment is a process of evaluating the effects that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities.

AI: Artificial intelligence refers to computer systems capable of performing complex tasks that historically only a human could do, such as reasoning, making decisions, or solving problems.

BREEAM: BRE Environmental Assessment Method was the first commercially available environmental assessment tool for buildings and has been the benchmark for methods for assessing the environmental aspects of sustainability of buildings since the first version for offices was launched in 1990.

INTRODUCTION

In the current discussion on sustainable design and environmental awareness, there is a growing interest in integrating greenery into built environments. In today's society, shaped by the challenges and stresses of urban life, there is a growing need for individuals to reconnect with nature. The fast-paced, concrete environments of cities distract us from the calming and renewing effects of the natural world.

Our homes and workplaces play a crucial role in shaping our well-being. Green wall systems offer an impressive solution to bridge the gap between our urban lifestyles and the healing qualities of nature. By bringing elements of the natural environment into our living spaces, these systems can create harmonious and healthy environments.

At the heart of supporting the incorporation of green wall systems into interiors is the belief that enriching our immediate surroundings with living, breathing greenery can have profound effects on well-being.

Moreover, as we grapple with the challenges of a rapidly urbanizing world, sustainable design practices are becoming crucial. Green walls contribute to this ethic by promoting energy efficiency, improving indoor air quality, and serving as an aesthetic manifestation of environmental awareness. The incorporation of plant life into interiors aligns with a broader commitment to creating sustainable, health-oriented living environments.

This thesis aims to investigate possible design solutions and future implications for green walls into interior spaces. The development of green walls, from their historical origins to modern interpretations, highlights a significant journey that goes beyond just visual enhancement.

This work comprehensively explore green walls, delving into their ecological, psychological, and spatial implications beyond their decorative function. By examining the historical background and core principles, the goal is to lay a strong groundwork for investigating modern design approaches. Acknowledging the various advantages and limitations linked with green walls, this thesis navigate through the complex set of needs, identifying crucial factors essential for the effectiveness of these living installations.

Moreover, an examination of different types of green wall variations seeks to condense the various approaches commonly found in this field.

The incorporation of green walls into indoor spaces is not just about appearance; it presents a multifaceted challenge that requires a detailed comprehension of gardening, architecture, and human engagement with the constructed surroundings. The framework for well-being in interiors seeks to identify the spatial dimensions of well-being and evaluate the importance of each spatial aspect that impacts our well-being in interior environments. The goal is to comprehend the factors that must be taken into account to promote well-being while incorporating green walls into indoor spaces.

THEORETICAL BACKGROUND

This chapter explores the theoretical principles that serve as the basis for investigating green walls in interior spaces. With the increasing popularity of incorporating nature into architectural design, it is crucial to comprehend the historical, definitional, and practical aspects of green walls.

The exploration starts with the origins of green walls, mapping out their development from ancient societies to contemporary uses. This historical progression not only emphasizes the lasting popularity of green walls but also demonstrates how their functions and cultural importance have changed over time. This section seeks to offer a thorough foundation, laying the groundwork for a more profound grasp of the current significance and utilization of green walls.

Following the historical background, it is important to clearly define what green walls are within the context of interior design. This section will outline the specific technical and conceptual characteristics that differentiate green walls from other biophilic design elements, providing a precise framework for subsequent discussions.

Finally, the advantages and drawbacks of green walls have been evaluated by referencing a diverse range of scholarly sources. This impartial view not only highlights the numerous benefits that green walls offer but also discusses the difficulties and factors to consider in their use. By examining both aspects, this section seeks to present a comprehensive understanding of green walls, providing valuable insights for designers, architects, and researchers regarding their potential effects and feasibility in indoor environments.

This chapter lays the foundation for comprehending green walls as a dynamic and versatile design solution in interior spaces by thoroughly examining these three crucial themes. The exploration of the theoretical background reveals the intricacy and diversity of green walls, facilitating informed application and advancement in sustainable design practices.

HISTORY OF GREEN WALLS

The historical lineage of green walls informs contemporary interior design by demonstrating a longstanding human preference for including natural elements in living spaces. Green walls have a long history, with their origins tracing back over 2500 years to the renowned Hanging Gardens of Babylon[1].

These gardens, one of the Seven Wonders of the Ancient World, showcased exceptional gardening skills and an early desire to incorporate nature's tranquility into human living spaces a concept that continues to influence modern interior design. Built around 600 BC, these magnificent gardens were an early example of vertical greening and featured tiered terraces with lush vegetation cascading down the walls, creating a stunning display of greenery[2].

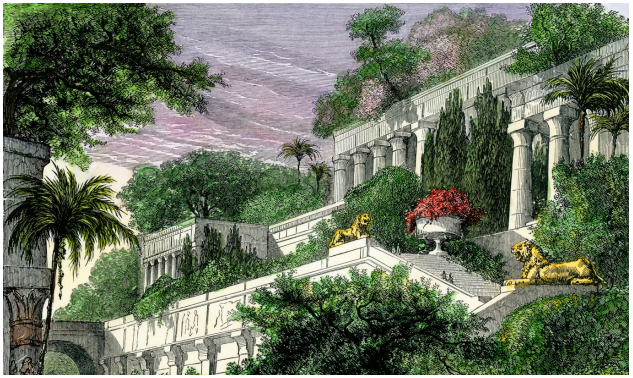

Figure 1.1: Site of the Hanging Gardens of Babylon

Green walls have been integrated into different architectural landscapes throughout history, including pre-Columbian America and ancient Indian architecture. The Romans showcased the integration of buildings with nature through expansive porticos and galleries leading to hanging gardens, while also incorporating trees in tombs and institutional structures.

[1] Weinmaster, Mike: Are green walls as "Green" as they look? An introduction to the various technologies and ecological benefits of green walls, in: Journal of Green Building, vol. 4, no. 4, 01.11.2009, [online] doi:10.3992/jgb.4.4.3, pp. 3–18.

[2] Donev N. Rise of a design feature: the astounding history of green walls. Designer Plants USA. Published March 16, 2023. https://designerplants.com/blogs/news/rise-of-a-design-feature-the-astounding-history-of-green-walls

The “Garden City Movement” inspired urban planning of the 19th century. The current idea of a garden within a interior is a product of the Art Nouveau movement [3]. These movements have impacted modern green wall designs by highlighting the significance of plant life in indoor spaces, not just for their visual appeal but also for their contribution to promoting healthier living environments.

Early 20th-century “organic architecture,” a movement that promotes the balance between human living spaces and the environment, was initiated by Scandinavian architects and American Frank Lloyd Wright. This movement continued to highlight the significance of plant life and the connection between nature and people through biophilic design principles[4].

Figure 1.2: Falling Water House by Frank Lloyd Wright

[3] Boby, N. M., Dash, S. P., Shetty, D (2020). An Overview of green wall systems: Its performance and benefits in sustainable design. https://archives.palarch.nl/index.php/jae/article/view/5608/5518

[4] The long history of Living walls. TERAPIA URBANA. Published July 17, 2023. https://terapiaurbana.es/de/the-long-history-of-living-walls/

In the 1930s, Stanley Hart White, a professor of landscape architecture at the University of Illinois developed a prototype for 'botanical bricks' patented as the Vegetation-Bearing Architectonic Structure and System (Fig.1.3) in 1938 which were the basis for the world's first known green wall or vertical garden, built in his own garden[5].

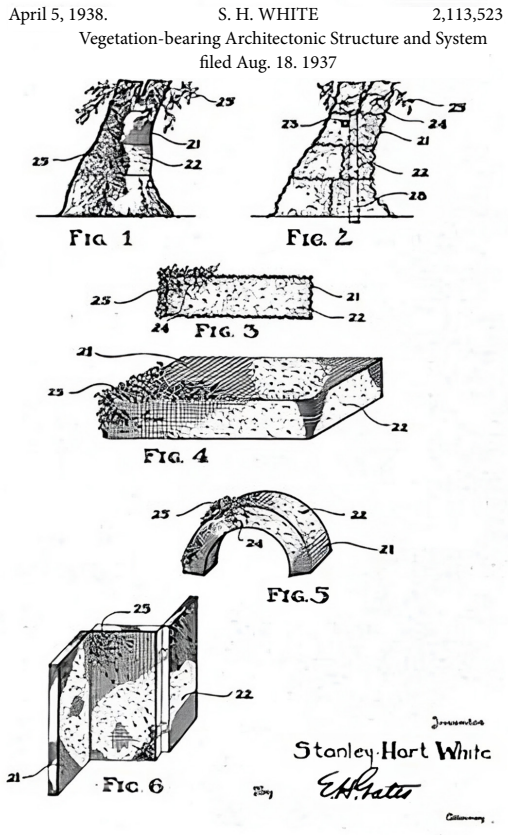

Figure 1.3: Vegetation Bearing Architectonic Structure and System by Stanley Hart White

[5] Pritchard & Pritchard. Published January 24, 2024. https://green-roofs.co.uk/stanley-hart-white-greenwallday-inventor-of-the-living-wall-february-15th/.

French botanist Patrick Blanc unveiled the first major vertical garden project at the Cité des Sciences et de l'Industrie in Paris in 1986, which revolutionized the use of green walls as a sustainable architectural treatment. Blanc's project marked a significant milestone in the development of vertical gardens[6]. His approach to vertical gardens as integral parts of building façades has translated into interior design, where living walls are now used as focal points that can transform the look and feel of a room. This pioneering work demonstrated how vertical gardens could be both sustainable and striking design features, leading to their adoption in interior spaces where space may be limited but the desire for greenery is high.

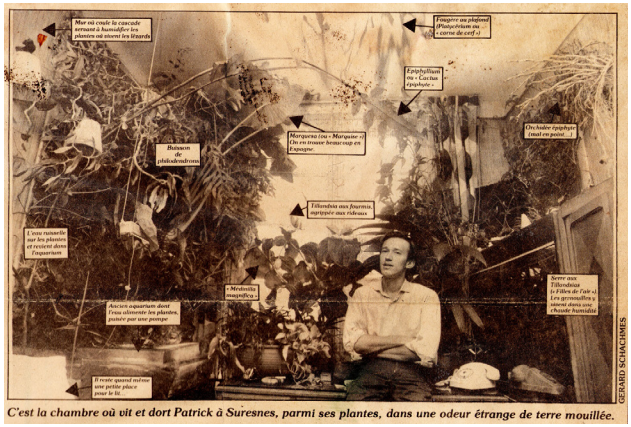

Figure 1.4: First vertical garden created by Patrick Blanc in his parent's home, Suresnes, 1978

[6] Morollo MK. 10 ways to create an uplifting vertical Garden. Dwell. Published June 22, 2017. https://www.dwell.com/article/10-ways-to-create-an-uplifting-vertical-garden-310d2f5e

The transition from ancient to modern uses of green walls demonstrates a growing inclination towards incorporating greenery as an essential and functional element in living spaces. This represents a shared desire for sustainable living practices and a stronger bond with nature principles deeply rooted in historical traditions but adjusted for the present era.

As city residents increasingly strive to harmonize the craving for nature with the restrictions of modern life, examining the historical background of green walls provides valuable insights. It reveals that integrating nature into our personal environments is not simply a current fad but has been a timeless feature of human habitat design one that continues to progress and adjust according to societal needs and values.

DEFINITION OF GREEN WALLS

A green wall, also known as a vertical garden, is a structure that incorporates various plant species and vegetation on the interior or exterior of a building[7]. According to Staffordshire University, a green wall is defined as: “Vegetation growing on or against a vertical surface”. Greenery is commonly planted in a growth medium of soil, stone, or water and frequently incorporate built-in irrigation systems, as a result of the presence of plants[8].

The indoor air biofilter (a special subgroup of living plant walls) integrates plants into the building’s air handling system as a living air filter. This biofilter combines two internal processing pathways: the first process, known as biofiltration, involves the flow of contaminated air through a biologically active material where beneficial microorganisms use pollutants (such as VOCs) as a food source. The second process, phytoremediation, utilizes green plants to support the growth of these helpful microbes[9].

Figure 1.5: A modern room featuring a vertical garden on the walls

7 Radić M, Dodig MB, Auer T. Green Facades and Living Walls—A review establishing the classification of construction types and mapping the benefits. Sustainability. 2019;11(17):4579. doi:10.3390/su11174579

8 Naava. What are Green Walls - the Definition, Benefits, Design, and Greenery. Published July 24, 2017. https://www.naava.io/editorial/what-are-green-walls

9 Arsenault, Darlington. Hydroponic living plant walls. Published July 2014. https://continuingeducation.bnpmedia.com/article_print.php?C=1100

Botanical biofilters have the potential to be used to reduce ambient indoor concentrations of NOx and O3. They act as a natural mechanism to purify the air by getting rid of small particles and reducing the level of CO2 in the environment[10]. This results in cleaner and healthier interiors in the long term.

"Research has shown that incorporating living walls into building design has several benefits: lowering energy consumption and greenhouse gas emissions, reduction of Urban Heat Island effect (UHI), increasing the thermal performance of buildings (lowering energy costs), positive effects on hydrology and improving water sensitive urban design (WSUD), improvement of Indoor Air Quality (IAQ), reduction of noise pollution, increasing urban biodiversity and urban food production, improvement of health and well-being" [11].

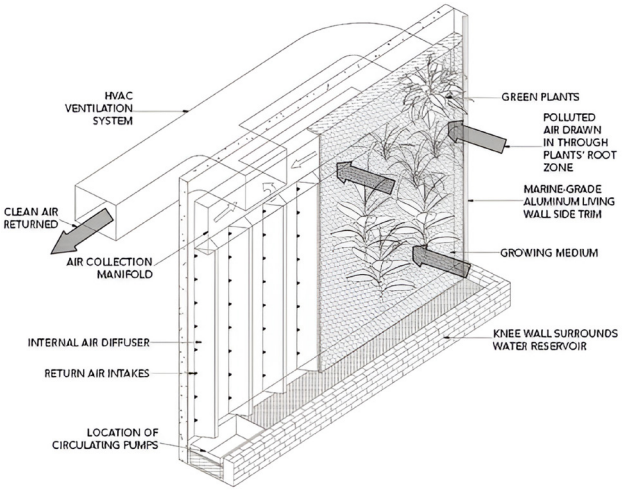

Figure 1.6: A hydroponic biofilter uses a combination of natural plant systems and manufactured air movement systems to move and filter air for superior indoor air quality.

[10] Pettit, T., Irga, P. J., Surawski, N. C., & Torpy, F. R. (2019). An Assessment of the Suitability of Active Green Walls for NO2 Reduction in Green Buildings Using a Closed-Loop Flow Reactor.

[11] Loh S. Living walls - a way to green the built environment. ResearchGate. Published online January 1, 2008. https://www.researchgate.net/publication/38183750_Living_walls_-_a_way_to_green_the_built_environment

The popularity of green walls has grown in recent years due to their environmentally friendly nature and visually pleasing qualities within interior spaces. They offer numerous benefits such as harmonizing with modern living, bringing natural elements into urban environments, reducing air pollution effects from city growth by compensating for reduced green spaces through vertical surfaces on walls, enhancing aesthetic appeal while promoting healthier indoor environments through sound insulation and temperature regulation.

Green walls have been shown to improve indoor air quality and conserve energy in buildings, reducing the reliance on electricity for heating and cooling systems this can lead to significant cost savings for interior spaces[12]. Green walls contribute to a calming atmosphere within interiors by evoking the freshness of nature, creating a connection between outdoor and indoor spaces, and providing a peaceful retreat from urban life.

Figure 1.7: A living room with floor-to-ceiling window showcasing a large green wall

[12] Energy EC. Green walls the green path to energy-efficient buildings. Utilities One. Published December 1, 2023. https://utilitiesone.com/green-walls-the-green-path-to-energy-efficient-buildings.

BENEFITS OF GREEN WALLS

Indoor Air Quality:

Green walls provide a notable benefit by serving as bio-filters, significantly enhancing indoor air quality. It has been observed that indoor environments can be up to ten times more polluted than the outdoors, which is commonly referred to as 'Sick Building Syndrome.' It is a matter of concern that people living and working in buildings made of manmade materials inhale over 300 contaminants every day[13]. The hypothesis that the toxicity of hundreds of different chemicals can add up to create major health hazards has raised concerns about these contaminants. On average, people spend over 90 percent of their time indoors. Indoor air pollution is a topic of concern due to the presence of various toxic fumes, including formaldehyde, VOCs, trichloroethylene, carbon monoxide, benzene, toluene, xylene, and others.

An active green wall could potentially assist the HVAC system in addressing these type of pollution. It may be possible to integrate it into a building's HVAC system by strategically placing fans behind the wall. These fans effectively draw air through the plant layer, which aids in the removal of harmful chemicals from the air. The resulting clean air is then circulated back into the building, significantly improving indoor air quality and ultimately benefiting the health of building occupants[14].

[13] Momtaz R.I. Vertical Garden as a Sustainable Urban Prespective in Cairo. JES Journal of Engineering Sciences,2018, p.246-262. doi:10.21608/jesaun.2018.114517

[14] Weinmaster, M. (2009). Are Green Walls as "Green" as They Look? An Introduction to the Various Technologies and Ecological Benefits of Green Walls.

Green walls can combat issues directly by naturally eliminating pollutants such as dust, toxins, and volatile organic compounds. The plants absorb these harmful particles through their leaves while their root microbes neutralize them, purifying the air and reducing health risks linked to indoor pollution[15]. Specific plant species are recognized for their phytoremediation abilities. For instance, Spathiphyllum, Epipremnum aureum (Devil's Ivy), Snake Plant, and Spider Plant have been documented for their capability to absorb and breakdown toxic chemicals such as benzene formaldehyde and trichloroethylene into non toxic by products[16]. Incorporating a variety of plant species into green walls allows targeting a wider range of pollutants given that different plants have diverse filtering capacities for specific contaminants.

[15] Eartheasy. Top 10 indoor plants for toxins | Eartheasy Guides & Articles. Eartheasy Guides & Articles. https://learn.eartheasy.com/articles/the-top-10-plants-for-removing-indoor-toxins/

[16] Caroline Design Editor. The Benefits of Air-Purifying Plants – A list of plants to improve your indoor air quality - TheDesigneur. Published July 7, 2023. https://thedesigneur.com/air-purifying-plants/.

Sustainable Living :

Green walls in interior spaces are vital in advancing our efforts toward environmental conservation and achieving sustainability goals. Green walls must be perceived as living elements essential for sustainability[17]. They contribute to this by effectively reducing emissions of greenhouse gases, fostering a diverse array of plant and animal life, and incorporating the use of recycled materials in their construction. Moreover, the implementation of sustainable irrigation systems is crucial as it ensures a reduced ecological footprint. They can help tackle wider environmental issues like wastewater management and play a role in enhancing the overall impact of green buildings at an urban level contaminants daily[18].

[17] Halaszova I, Kozlovská M. Sustainability of green walls. IOP Conference Series: Materials Science and Engineering 2021. doi:10.1088/1757-899X/1209/1/012070

[18] Yadav RK, Sahoo S, Yadav AK, Patil SA. Green wall system coupled with slow sand filtration for efficient greywater management at households. Npj Clean Water. 2023;6(1). doi:10.1038/s41545-023-00285-3

The LEED Certification:

The Leadership in Energy and Environmental Design program, established by the U.S. Green Building Council, is a globally acknowledged certification system for sustainable building practices. Implementing living green walls can contribute towards earning LEED points for buildings, enhancing their perceived value and environmental impact. Furthermore, commercial properties with LEED certifications may qualify for tax credits based on their rating.

The WELL Certification

The WELL certification system is designed to assess and improve building performance, prioritizing human well-being and productivity over environmental sustainability, distinguishing it from LEED. This approach revolves around seven fundamental principles for evaluating, certifying, and overseeing our workspaces. The core concepts of the WELL Building Standard provide a framework for enhancing human health and wellness in the built environment - covering air quality, water quality, healthy nourishment options, lighting design that supports circadian rhythms, physical activity opportunities at work areas offering ergonomic comfort solutions' support for mental well-being[19].

[19] Rentokil Initial. How living green walls provide indoors benefits and more. . https://www.ambius.com/plant-design/green-walls/benefits

Aesthetic Improvement:

Green walls have the potential to enhance aesthetics by imitating the natural environment. They introduce elements of nature and beauty into indoor spaces, creating visually pleasing displays that can help to promote a peaceful and soothing ambiance. These living installations are able to convert ordinary walls into visually pleasing displays, creating a peaceful and soothing ambiance in any environment.

Economic Benefits:

Green walls can result in considerable reductions in utility bills by decreasing the energy needed for heating and cooling[20]. A study conducted by the University of Technology Sydney found that green walls have the potential to reduce cooling energy consumption by up to 25%; in addition, green walls are highly desirable to prospective buyers and tenants due to their aesthetic appeal and environmental benefits; properties with green walls have been observed to have higher resale values and rental rates[21].

The U.S. Green Building Council created the LEED program to promote sustainable building through a certification system that rewards green design, construction, and operation practices. Both commercial and residential property owners can earn LEED credits by meeting specific environmental criteria. Installing living green walls indoors can earn points for low water usage and efficient irrigation, demonstrating commitment to sustainability. This helps enhance property value by presenting a modern building with a reduced carbon footprint[22].

[20] Loh S. Living walls - a way to green the built environment. ResearchGate. Published online January 1, 2008. https://www.researchgate.net/publication/38183750_Living_walls_-_a_way_to_green_the_built_environment

[21] Energy EC. Exploring the financial benefits of green walls for energy-conscious investors. Utilities One. https://utilitiesone.com/exploring-the-financial-benefits-of-green-walls-for-energy-conscious-investors. Published December 1, 2023.

[22] Ultimate Guide to Living Green Walls: What are They? Rentokil Initial. https://www.ambius.com/resources/plant-care/ultimate-guides/green-walls

Well-Being Impact:

Numerous research studies have shown that the presence of indoor vertical greenery can have a positive impact on individuals' well-being, offering visual satisfaction and associated restorative advantages. Introducing living walls in indoor spaces has been connected to improved emotional wellness and revitalized cognitive energy, as indicated by responses to engaging with an indoor vertical greenery system. The visual pleasure and therapeutic benefits offered by indoor vertical greenery help create a more calming and uplifting atmosphere indoors, ultimately promoting the overall health and well-being of individuals[23].

"When plants were introduced into this interior space, participants showed increased productivity (12% quicker reaction time on the computer task) and reduced stress levels (systolic blood pressure readings lowered by one to four units)"[24]. On average, people spend approximately 90% of their time indoors in artificial environments; it is crucial to enhance the quality of these spaces where people live and work. Plants possess the ability to absorb, scatter, and reflect sound waves; their effectiveness is influenced by factors such as sound frequency and room structure [25].

[23] Liu X, Wu R, Huang J, Yang X, Xu A. Study on the Relationship between Restoration Benefit and Visual Satisfaction of LONG-PLAN's Indoor Vertical Greenery. Buildings. 2022;12(8):1267. doi:10.3390/buildings12081267

[24] Lohr VI, Pearson-Mims CH, Goodwin GK. Interior plants may improve worker productivity and reduce stress in a windowless environment. Journal of Environmental Horticulture. 1996;14(2):97-100. doi:10.24266/0738-2898-14.2.97

[25] Learn about 9 Benefits of an Indoor Living Green Wall -. Biotecture. Published February 9, 2021. https://www.biotecture.uk.com/benefits-of-green-walls/benefits-of-interior-living-walls/

The quantity, size, and surface area of plants contribute to their capacity for absorbing sound while impacting room acoustics through decreased reverberation time. Especially in acoustically lively spaces with hard surfaces like marble walls or stone floors, plants play a significant role in shaping room acoustics. Their presence provides environmental benefits that can positively influence physical well-being by improving air quality which may help reduce headaches; visual exposure to plants also contributes to mental well-being by reconnecting us with nature[26].

[26] Freeman K. How plants can reduce noise levels indoors. HuffPost UK. Published April 19, 2014. https://www.huffingtonpost.co.uk/kenneth-freeman/how-plants-can-reduce-noi_b_4802876.html

LIMITATIONS OF GREEN WALLS

High Initial Cost:

It is crucial to assess the long-term maintenance requirements and costs associated with different types of green wall systems[27]. One downside that needs consideration is the high initial cost for installation, which may pose a barrier for buyers. Continuous maintenance costs including lighting and irrigation needs of the plants must be carefully factored in as well[28]. These expenses add significantly to the overall financial commitment of upkeeping a living wall in interior settings. Considering these factors can help designers and buyers make informed decisions about whether a green wall system is suitable for their specific needs and preferences.

Maintenance:

Maintenance challenges in indoor living wall systems often revolve around the difficulty of watering plants located in elevated positions, which can lead to potential plant wilting. To ensure the successful implementation of a interior living wall system, it is important to carefully assess and plan for maintenance needs and challenges that may arise. Moreover, maintaining a healthy indoor living wall requires regular responsibilities such as irrigation, inspecting drainage systems, pruning, and occasional replacement of plants. In addition, it is important to consider the budget and available resources for maintenance, as well as the expertise and knowledge of horticultural practices in interior spaces[29].

[27] Manso M, Castro-Gomes J. Green wall systems: A review of their characteristics. Renewable & Sustainable Energy Reviews. 2015;41:863-871. doi:10.1016/j.rser.2014.07.20

[28] Abernethie B. Moss walls vs. Living walls - Advantages and Disadvantages - Leaflike. Leaflike. Published November 15, 2022. https://www.leaflike.co.uk/moss-walls-vs-living-walls/

[29] Woods R. How Living Plant Walls are Damaging Buildings. https://www.evergreenwalls.com.au/blog/living-plant-walls-damaging-buildings

Uncontrolled Plant Growth:

Plants have a natural inclination to seek sunlight and can grow in an unregulated way. If not properly managed, this growth can lead to plants extending towards windows, blocking views and creating uneven coverage on the wall[30]. However, choosing and maintaining plants carefully for green walls can help control their growth and prevent obstruction of views. One effective way to control the growth of plants in green walls is to select species that are known for their compact growth habits which can help prevent the green wall from becoming overgrown and encroaching on the living space. Additionally, regular pruning and maintenance can help ensure that the plants remain at an appropriate size and shape.

Irrigation:

Proper irrigation methods are crucial to prevent structural water damage and the development of mold, which can pose risks to both the building and its occupants[31]. Maintaining a vertical wall garden presents a significant and complex task in terms of watering the plants. Ensuring the survival of the plants demands adequate water supply and effective drainage, which can be quite difficult when setting up the living wall. Similarly, it is essential to prepare the indoor space for the vertical garden properly to prevent moisture-related issues. This may involve implementing waterproofing measures around and within the vertical garden to safeguard against water damage. These considerations pose continual challenges and potential additional costs that should be carefully evaluated alongside the numerous advantages associated with vertical wall gardens.

[30] Mindbase. Pros and cons of indoor vertical gardens. Custom Home Group. Published May 18, 2023. https://www.customhomegroup.com/blog/pros-and-cons-of-indoor-vertical-gardens/

[31] Cartwright D. Living Green Walls are Causing Serious Structural Issues. https://www.buildsoft.com.au/blog/living-green-walls-are-causing-serious-structural-issues

GREEN WALL SYSTEM

This chapter aims to analyze the complex elements and factors involved in effectively integrating green walls into interior environments. By exploring system requirements, plant choices, and different types of planting systems.

The exploration begins with a look at the essential green wall system requirements, covering critical aspects such as the growing medium, irrigation, lighting, structural support, and maintenance. Each element is crucial for the vitality and longevity of a green wall, ensuring its aesthetic appeal and environmental benefits endure over time.

The focus then turns to “Choosing Plant Types for Indoor Green Walls,” presenting a selected table of appropriate indoor plants. This section emphasizes the importance of selecting the right plant species that align with aesthetic preferences, environmental conditions, and maintenance requirements in order to ensure the success and longevity of the vertical garden.

Further, the discussion extends to green wall system types, identifying and describing 11 systems of green walls tailored for interior spaces. Each system is illustrated with examples, offering a practical insight into the diversity and applicability of green wall technologies across different indoor settings.

It then delves into the advantages and disadvantages of system types, offering a balanced perspective that helps in choosing the most suitable green wall system based on specific project needs, challenges, and objectives.

In categorization of the systems, a unique approach is introduced, positioning green wall systems within the spatial dynamics of interior design. This section includes a table that explains the role of green wall systems beyond mere decoration, highlighting their significance in addressing spatial considerations and improving interior environments.

The chapter concludes with an examination of the well-being framework on system typologies, which delves into the emotional, contextual, operational, psychological, social, sensory, aesthetic, and ergonomic aspects of green wall systems. Through an analysis using a well-being framework approach, the study examines how various system typologies address a range of well-being needs. It provides valuable insights into the significant influence of green walls on human health and happiness in constructed environments.

This chapter not only seeks to educate but also to stimulate interest in adopting and creatively applying green wall systems in interior design. By engaging with these discussions, readers will develop a deep understanding of the complexities as well as benefits associated with green walls. This knowledge can aid to incorporate these living structures in ways that combine visual appeal with functional and psychological well-being

SYSTEM REQUIREMENTS

Growing Medium:

Growing medium are the substances utilized to facilitate plant development in different settings. They offer a firm foundation for the roots to establish and flourish, while also enabling water retention and absorption of vital nutrients. The selection of growing media can have a considerable effect on plant well-being, development, and overall performance.

Soil-based growing medium is the most commonly utilized substrate in living walls. It is a combination of organic materials, like compost, mixed with soil to establish an optimal environment for plant growth. This type of medium supplies vital nutrients and holds moisture, supporting the health and development of plants. Nevertheless, its weight can potentially affect the structural demands of the living wall.

Soilless growing medium includes substances such as peat moss, coconut coir, perlite, Rockwool, and compost. These materials provide a foundation for root growth while preserving moisture and vital nutrients. Unlike soil-based media, this type of medium does not contain inherent nutrients and therefore needs the addition of fertilizers for plant cultivation. As a result, it allows more accurate regulation of nutrient levels than traditional soil-based mediums do a feature that can be advantageous in controlled environments or hydroponic systems[32].

Hydroponic growing medium entails the growth of plants without relying on soil. Discovered by the French botanist Patrick Blanc, these innovative systems are irrigated with water enriched with nutrients, and plant roots develop within layers of matted or felted substrate [33].

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[32] Choosing planting systems and growing media for living walls. Eco Brooklyn. Published August 18, 2023. https://ecobrooklyn.com/living-wall/planting-systems-growing-media-living-walls/

[33] Riley B, De Larrard F, Malécot V, Dubois-Brugger I, Lequay H, Lecomte-Nana GL. Living concrete: Democratizing living walls. Science of the Total Environment. 2019;673:281-295. doi:10.1016/j.scitotenv.2019.04.065

In Hydroponics, a carefully designed liquid mixture that contains vital minerals and vitamins is utilized to provide nourishment to the roots of the plant. Within hydroponic living wall systems, this nutrient solution is distributed to an artificial growing medium such as rock wool or geo-textile fabric through an irrigation system. Plants require water, air, light, nutrients and structural support in order to thrive effectively. In Hydroponic systems, the focus is on utilizing an inactive rooting material as a supportive medium for plants while administering necessary nutrients through irrigation. In this method, the role of “soil” is minimized to primarily serving as a support system to keep the plant in place.

The plants are cultivated in an inactive rooting material with limited water retention and solely serve as a means to uphold the plant vertically. All vital nutrients must be provided through the irrigation water in hydroponic setups which can be structured as a closed loop where used water and its contained nutrients are gathered and circulated back through the system, optimizing plant production. Utilizing simple synthetic inactive media enables direct monitoring of conditions within the root environment, fostering efficient resource utilization by considerably reducing water and nutrient usage, aligning effectively with sustainable design principles applicable to vertical planting venues [34].

Living wall vegetation requires a growing substrate for the roots to anchor into. The growth medium is typically installed on a framework (such as containers, pots, or boxes) that collectively create a system. These arrangements are available in various forms and can generally be classified into four categories: loose, mat, sheet, and structural media systems [35].

[34] Arsenault, Darlington. Hydroponic living plant walls. Published July 2014. https://continuingeducation.bnpmedia.com/article_print.php?C=1100

[35] Naava. What are Green Walls - the Definition, Benefits, Design, and Greenery. What are Green Walls - the Definition, Benefits, Design, and Greenery. Published July 24, 2017. https://www.naava.io/editorial/what-are-green-walls#:~:text=Green%20walls%20are%20vertical%20structures,feature%20built%2Din%20irrigation%20systems.

Loose growth medium setups involve packing soil into a shelf or bag and then placing it on a wall, while mat media consist of thin coir fiber or felt mats where plants root directly without needing loose soil. Sheet media are similar to mat systems but use patterned inorganic polyurethane sheets that are more durable than coir fiber or felt. Structural media combine both loose and mat systems by forming blocks that can be molded into various shapes and sizes. For instance, the plants can be planted in loose soil, put into pots, and attached to a wall structure with built-in irrigation.

Loose planting materials such as soil, hydro stone, volcanic stone, and hydroponics are commonly utilized in flexible media systems for plant growth. Conventional green walls typically rely on rockwool or soil as their choice of growth media. These materials have long been standard in the plant industry because hydroponics is often seen as challenging due to numerous factors associated with water quality. The majority of green wall creators make use of readily accessible growth media from established markets.

Growth media in green walls differ from those found in regular ones. They need a specialized material to ensure adequate airflow, as well as stable and effective microbial communities and water systems. The growth medium, support systems, structures, and plants all need to work together harmoniously. Therefore, the choice of media cannot be made independently of other factors [36].

[36] Naava. What are Green Walls - the Definition, Benefits, Design, and Greenery. What are Green Walls - the Definition, Benefits, Design, and Greenery. Published July 24, 2017. https://www.naava.io/editorial/what-are-green-walls#:~:text=Green%20walls%20are%20vertical%20structures,feature%20built%2Din%20irrigation%20systems.

Irrigation System:

Living wall system installations need an irrigation system to support plant growth. Water can be enriched with nutrients, fertilizers, phosphates, amino acids, or hydroponic elements in order to enhance the vitality and development of plants[37].

Irrigation systems for vertical gardens can be classified into recirculating and direct systems. Most vertical gardens are controlled by a timer, regulating the irrigation cycles to ensure that various sections of the garden receive water at appropriate intervals.

Recirculating systems are defined by the presence of an irrigation tank, usually positioned either at a distance or directly below the green wall.

These setups depend on consistent manual replenishment to ensure adequate irrigation supply. The water is pumped to the plants and any excess is recaptured at the bottom of the wall, to be reused, making this an efficient system in terms of water conservation

Direct irrigation differs from recirculating systems in that it does not require a water tank or pump. Instead, water is obtained directly from an external source and then distributed to the plants. This system relies on the inherent water pressure for distribution and often does not recirculate excess water, which is instead drained away[38].

Additionally, the water flow rates and the distribution uniformity are essential for optimizing the performance of the irrigation system, which can be influenced by factors such as substrate type and plant location[39].

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[37] Manso M, Castro-Gomes J. Green wall systems: A review of their characteristics. Renewable & Sustainable Energy Reviews. 2015;41:863-871. doi:10.1016/j.rser.2014.07.203

[38] Rentokil Initial. How green walls work: Understanding irrigation systems. . https://www.ambius.com/plant-design/green-walls/irrigation

[39] Pérez-Urrestarazu L, Egea G, Franco-Salas A, Fernández-Cañero R. Irrigation systems evaluation for living walls. Journal of Irrigation and Drainage Engineering-asce. 2014;140(4). doi:10.1061/(asce)ir.1943-4774.0000702

Lighting System:

Light is a fundamental requirement for photosynthesis, the provision of sufficient lighting is essential to maintain plant health and facilitate CO2 removal[40]. Some studies indicate that adjusting lighting to match the natural circadian rhythms of plants may boost their growth and flowering. This can be accomplished using automated systems that regulate light intensity and color temperature at different times during the day. The specific lighting design depends on factors such as the size of the wall, its dimensions, and the desired level of illumination. The choice of lighting should simulate the natural light spectrum as closely as possible to support photosynthesis and maintain natural growth patterns. Adequate lighting plays a vital role in ensuring healthy plant growth, and it is recommended to consult with design experts who have specialized knowledge in irrigation, horticulture, and structural engineering to determine the appropriate type and amount of light needed[41].

[40] Dominici L, Fleck R, Gill RL, et al. Analysis of lighting conditions of indoor living walls: Effects on CO2 removal. Journal of Building Engineering. 2021;44:102961. doi:10.1016/j.jobe.2021.102961

[41] Lighting assessments for living walls. Scotscape. https://www.scotscape.co.uk/blog/lighting-assessments-for-living-walls

Structural Support:

The structural design plays a crucial role in determining the durability and effectiveness of living walls. The construction and support of these structures are pivotal in ensuring their resilience against environmental factors and longevity. The stability and long-term viability of any structure depend significantly on its foundation, and this principle applies to living walls as well. When creating a living wall, it is crucial to establish a robust and secure base capable of bearing the weight of the plants and growth medium. A weak foundation may lead to issues like tilting, structural damage, or potential collapse in living walls. Use of structural reinforcements such as steel beams or reinforced concrete to maintain the stability of the vertical garden. Perform soil assessment and engineering evaluation to determine the appropriate load-bearing capacity of the foundation[42]. Implement efficient waterproofing and drainage systems to reduce water buildup, which could compromise the strength and durability of the structure.

A well-thought-out strategy for preserving a green wall is best formulated during the planning stage. It should encompass methods to ensure the wall's health and vitality, as well as risk mitigation measures to minimize potential injuries and property damage during maintenance activities. Similar to any natural green area or garden, without adequate care and attention, a green wall will deteriorate over time.

[42] Energy EC. Structural integrity considerations in green roofs and living walls. Utilities One. https://utilitiesone.com/structural-integrity-considerations-in-green-roofs-and-living-walls. Published December 1, 2023.

Maintenance:

To promote the long-term health of green walls, it is important to ensure proper maintenance. It is recommended that users are aware of their ongoing maintenance responsibilities. Typical maintenance tasks include managing weed growth, trimming, applying mulch, disposing of waste, inspecting plants for signs of illness or stress, introducing new plants or replacing existing ones to maintain the density of the structure, preventing plant encroachment into fixtures like windows or drains, clearing dry vegetation, ensuring proper watering to minimize fire hazards, and assessing the support framework for any damage or loose connections and carrying out necessary repairs[43].

[43] Bottero P, Bottero P. A Guide to Maintaining Green Walls | Tensile Design & Construct. Tensile Design & Construct | Tensile Architectural Solutions Suppliers & Installers. Published March 14, 2018. https://www.tensile.com.au/a-guide-to-maintaining-green-walls/

PLANT TYPE SELECTION

Choosing the right plants for the specific conditions of vertical green systems is essential for their successful performance. Indoor coordination plants used to purify the air are scientifically known as biofilters, or with biological therapy the use of plants in the indoor environment is one of the most important reasons that work to achieve the quality of the internal environment by achieving the environmental standards set by Leadership in Energy and Environmental Design (LEED), which include quality[44].

Researchers from the State University of New York recently conducted a study focusing on identifying plants with the capacity to absorb volatile organic compounds. These pollutants, which can be found in paint, furniture, printers, dry cleaned clothes, and various household products, are potentially harmful. High levels of VOCs can result conducted precise of five different types of indoor plants experiments to assess the effectiveness in health issues like light headedness, Vadoud Niri and his research team including the jade plant, spider plant, bromeliad, dracaena, and Caribbean tree cactus. Each plant was placed in a sealed chamber with specific concentrations of various VOCs. The researchers monitored air quality over time to determine each plant's ability to purify the air.

The bromeliad demonstrated notable performance by removing 80 percent of pollutants across six out of eight tested VOCs. Similarly, other plants exhibited high efficiency in targeting specific pollutants; for instance, the dracaena effectively absorbed 94 percent of acetone, a chemical commonly found in nail polish remover. Additionally, spider plants showed rapid activity in eliminating VOCs shortly after being introduced into their environment[45].

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[44] Sultan AAF. Green interior walls and their use in sustainable commercial spaces. International Journal of Advanced Research on Planning and Sustainable Development. 2022;5(1):41-60. doi:10.21608/ijarpsd.2022.274362

[45] Nield D. These are the best houseplants to improve indoor air quality, study finds : ScienceAlert. Published August 26, 2016. https://www.sciencealert.com/the-right-house-plants-could-improve-indoor-air-quality-researchers-say

The latest research compared common indoor plants including Devil's ivy, Arrowhead plants, and Spider plants with petrol vapors, a major source of various volatile organic compounds. According to UTS environmental scientist Fraser Torpy, "Plants not only efficiently remove the majority of air pollutants within hours, but they also effectively eliminate the most harmful petrol-related pollutants from the air.

"Torpy and his team conducted experiments on the Ambius vertical plant wall system using nine custom-designed perspex boxes containing either four plants or no plants. A small amount of petrol was vaporized inside these chambers, and researchers then measured the gas levels. Despite a slight decrease in gases in the control chamber leading to suspicions of a leak in each test box, researchers remain confident that during an 8-hour period almost half (43%) of total VOCs were removed by the plants. Moreover, nearly all alkanes (98% removed), benzene derivatives (86%), and cyclopentanes (88%) which are particularly harmful chemical classes were eliminated. This removal of airborne contaminants could have significant implications for maintaining a healthy indoor environment due to their potential adverse health effects"[46].

[46] Watson C. Plants can clean toxic chemicals from the air in hours, study shows : ScienceAlert. ScienceAlert. Published June 6, 2023. https://www.sciencealert.com/plants-can-clean-toxic-chemicals-from-the-air-in-hours-study-shows

Plant Types	Light Requirement	Watering Need	Humidity Tolerance	Additional Notes
Pothos 	Low-light requirements /thrives in shaded areas	Low water/high drought tolerance	Moderate humidity/ is not tolerant to cold temperatures below 10 C	The foliage of the plant has a tendency to extend outward, offering effective coverage and medium texture for the wall.
Philodendron 	Low-light requirements / thrives in indirect sunlight	Low-water needs	Moderate humidity/ should not be exposed to temperatures below 13 C	Leaves descend and contribute to filling the area. This plant is most suitable for the upper section of the wall.
Ferns 	Low-light requirements / thrives in shaded areas	Low water needs.	Moderate humidity/ prefers temperatures between 18 and 24 C	Leaves have a tendency to extend outward and offer protection for the wall.
Spider Plant 	Low-light requirements / thrives in shaded areas	Low water needs. It has a high drought tolerance.	Moderate humidity/ is not tolerant to cold temperatures below 10 C	Leaves may descend along a vertical surface and offer concealment for the wall. It is most suitable for the upper section of a wall.
Nephthytis 	Low-light requirements	Low water needs	Moderate humidity/ prefers temperatures above 15 C	Leaves have a downward growth pattern, making this plant best suited for placement at the top of the wall. There exists a wide range of varieties to choose from.
Dracaena 	Low light requirements / thrives in shaded areas	Water to keep soil moist but never soggy	High humidity/ thrive at temperatures of 20 to 26 C	Plant leaves have a tendency to grow upward, so it is advisable to position this plant at the base of a wall.
Peace Lily 	Bright, indirect light needs. More light leads to more flowering	Low water needs.	High humidity/ prefers temperatures between 18 to 27 C	Is ideal for compact walls.
Calathea 	Filtered light/indoor light. Thrives in shaded areas	Low water needs; keep soil moist	High humidity/ prefers temperatures between 20 to 30 C	This plant thrives when grown in pots or containers.
Prayer Plant 	Low/indirect light . Too much direct light can cause the leaves to become bleached	Low water needs; prefers moist soil.	Moderate humidity/ prefers temperatures between 15 and 26 C	Leaves tend to grow down/cascade which assists to cover the wall. Suitable for indoor and container planting.
Chinese Evergreen 	Low light needs/ Requires shade	Moderate water needs	High humidity/ should not be exposed to temperatures below 20 C	Leaves are a simple spiral pattern of green foliage. High light causes the leaves turns yellow.

Table 1: Plant types for indoor green walls
(Indoor Plant Guide by Suite Plants) LivePanel system for any indoor or outdoor space. Suite Plants - Green Wall Experts. https://www.suiteplants.com/livepanel
Houseplants: Care & Growing Guides. The Spruce. Published June 15, 2023. https://www.thespruce.com/houseplants-4127735

A variety of plant species suitable for incorporation into indoor living walls are compared in the Table 1 based on their growing needs and ability to tolerate different environmental conditions. The selection includes plants with a range of light, water, and humidity requirements, providing choices for a wide range of indoor environments.

The majority of plants, such as Pothos, Philodendron, Ferns, Spider Plant, Nephthytis, and Dracaena prefer low-light conditions. This makes them suitable for areas with limited natural light. On the other hand, the Peace Lily thrives in bright indirect light and is known to bloom more profusely under increased brightness.

When assessing the water requirements, all the listed plants show a common preference for low water needs, indicating their ability to adapt to the low-maintenance conditions of a living wall. However, there are differences observed; for example, the Spider Plant and Philodendron have strong resistance to drought, while the Calathea and Prayer Plant require consistently moist soil, highlighting the importance of careful watering techniques.

Differentiating the species goes further when considering their tolerance to humidity. For example, the Dracaena and Peace Lily thrive in high humidity with optimal temperatures ranging from 20 to 26°C and 18 to 27°C respectively. On the other hand, plants such as Pothos and Spider Plant show moderate tolerance to humidity and a remarkable ability to withstand lower temperatures.

Crucial insights about growth patterns and spatial considerations are provided in additional notes. For example, the Pothos and Philodendron have foliage that extends outward, effectively covering walls. In contrast, the Spider Plant and Nephthytis demonstrate downward growth, making them suitable for higher placement where they can cascade elegantly.

The comparison reveals the varied needs and growth patterns of plants, offering a strategic basis for creating an indoor living wall. Careful selection ensures a sustainable and visually unified installation that suits the particular climate and space limitations indoors.

GREEN WALL SYSTEM TYPES

POD Living Wall System:

In the POD living wall system, plants are placed in pots and watered from above. This system addresses common challenges of standard live wall systems by extending plant lifespans and preventing pests, blockages, and frequent replacements. The enclosed design keeps plants secure against wind or impact. Replacements and modifications are easily facilitated by this system's design as water flows down through each pod behind the plants before draining out at the bottom into a collection basin or back into internal plumbing. The enclosed irrigation system prevents blockages caused by leaves and debris, reducing maintenance requirements. Pods' modular nature allows them to accommodate various shapes while maintaining separate water flow within each pod to avoid clogging from mulch formation"[47].

Figure 2.1: Pod system by Green Oasis

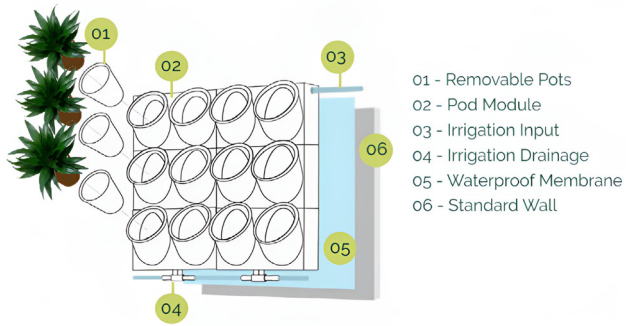

Figure 2.2: Schematic of a Pod living wall system with labeled components

[47] POD Living Plant Wall System | Green Oasis. Green Oasis. Published December 28, 2023. https://greenoasis.com/living-walls/pod-living-plant-wall-system/

Location: San Antonio, Texas
Client: Fasken Oil and Ranch
Installation: -
Project Specialist: Mike McAbery, Green Oasis

The use of the POD Living Wall System in WellMed Lobby, a LEED-certified building, combined natural elements with sustainable architecture. The project aimed to create ground floor spaces that foster social interaction and provide a peaceful environment through live plant installations. Extensive care was taken in selecting plant species and layouts to ensure the plants' healthy growth and long-term durability. Considerations such as available sunlight and airflow were crucial for maintaining the living wall's health, resulting in a well-curated collection of plants that enhanced the communal areas of the building while aligning with sustainability principles [48].

Figure 2.3: Pod system living wall for entrance wall of Fasken Oil and Ranch by Green Oasis

Figure 2.4: Completed Pod system living wall for Fasken Oil and Ranch by Green Oasis

Figure 2.5: Incompleted Pod system living wall for Fasken Oil and Ranch by Green Oasis

[48] Living Plant Wall and Peninsulas | Green Oasis. . https://greenoasis.com/nrcc-living-plant-wall-and-peninsulas/

Trellis System:

Trellis systems provide a unique method for integrating plants into indoor environments. These systems, known for their grid or cable-like structure, enable climbing plants to thrive and offer self-support. Planters are strategically positioned at the bottom of the trellis, with vines taking approximately 8-10 months to completely cover the wall[49].

Compared to other living wall options, trellis systems often necessitate manual watering based on natural conditions. Furthermore, they offer a financial benefit as these systems are more cost-effective than conventional alternatives. This cost efficiency makes them particularly suitable for projects with budgetary constraints[50].

Figure 2.6: Trellis System in the living room

Figure 2.7: Botanical Planter Screens by Helen Kontouris

[49] Turner L. An architect's guide to: Living Wall Systems — Urbanstrong. Urbanstrong. Published February 9, 2022. https://urbanstrong.com/blog/an-architects-guide-to-living-wall-systems

[50] Sharp D. Trellis green walls vs pocket based green walls. Green Walls. Published April 12, 2021. https://green-walls.co.uk/blog/trellis-green-walls-vs-pocket-based-green-walls/

Location: Melbourne, Australia
Client: City of Stonnington
Installation: 2015
Project Specialist: Fytogreen & Philip Johnson

The City of Stonnington has used a trellis green wall system in the redevelopment of its council building, aimed at creating durable and aesthetically pleasing green infrastructure. The vertical cabling system by Tensile serves as both structural support for botanical climbers and planters provided by Fytogreen[51].

The design criteria required the cable balustrades to withstand dynamic loads imposed by plant growth over time, leading to precise engineering and installation. This design provides structural strength without being visually obtrusive, while keeping the interior open and filled with natural light.

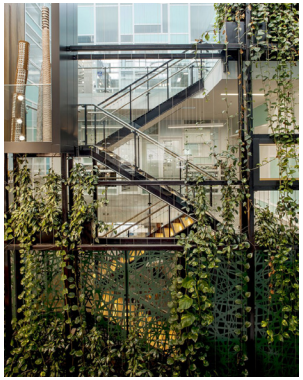

Figure 2.8: Interior view of the Stonnington City Council Office atrium with trellis green walls flanking the staircase.

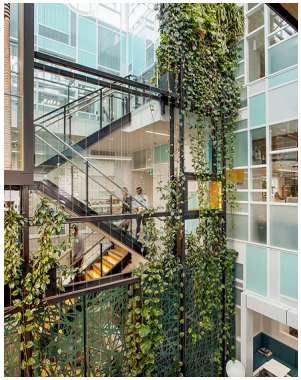

Figure 2.9: Stonnington City Council Office landing featuring a trellis green wall under natural light.

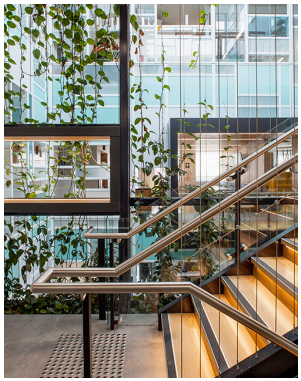

Figure 2.10: Green walls surrounding the office space, viewed from the staircase landing.

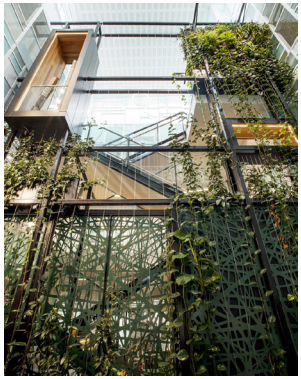

Figure 2.11: Detailed view of a trellis green wall in Stonnington City Council Office.

[51] Tensile Design & Construct. Internal Green Wall Project | Tensile Design & Construct. Tensile Design & Construct | Tensile Architectural Solutions Suppliers & Installers. Published November 28, 2023. https://www.tensile.com.au/project/stonnington-city-council-office/

Moss Wall:

A moss wall is a decorative element comprised of preserved moss mounted onto backing boards or panels. These walls are designed for decorative use in interior spaces, offering a versatile and aesthetically pleasing way to bring natural greenery indoors.

Moss walls are not “alive” but are made of 100% natural moss that has been carefully preserved through an eco-friendly process, making them maintenance-free and long-lasting. Moss walls provide the creativity of artwork, the freshness of live plants, and the convenience of artificial plants, supporting the biophilia theory of bringing nature indoors and improving overall wellness[52].

Figure 2.12: Rio Azul Moss Wall Art by Moss Art Installations

[52] Fotex. The Ultimate Guide for Moss Walls 2021 - Greenleaf IPS - blog. Greenleaf Interior Plant Solutions. Published February 1, 2021. https://www.greenleafips.com/the-ultimate-guide-for-moss-walls-2021/

Location: -
Client: Hurtigruten Group
Installation: -
Project Specialist: Leaflike

A moss wall combining flat moss, reindeer moss, and bun moss with the company branding. This low-maintenance planting solution is designed to be aesthetically pleasing in an office environment.

The office space is designed to incorporate nature with carefully selected plants, promoting a harmonious balance between aesthetics and functionality. The presence of biophilic design has been proven to enhance productivity by reducing stress, improving air quality, and fostering well-being among employees. This includes a moss wall adorned with the company branding for high impact, low-maintenance greenery in the office environment[53].

Figure 2.13: Moss Wall at Hurtigruten Group Office

[53] Clarke L. Hurtigruten Group - Leaflike. Leaflike. Published June 5, 2023. https://www.leaflike.co.uk/hurtigruten-group/

Smart Wall:

These walls are connected to the cloud and there is a monitoring system that synchronously follows the well-being of the plants. Given these characteristics, the plants receive light, water and nutrients only when it is essential. Coupled fans are used to promote circulation of filtered air throughout spaces. Each wall removes up to 57% of harmful chemicals on the first pass of air through the system.

As this is a continuous system, air quality filtration is promoted with each use, benefiting from adjustments to the humidity of the air and the circumstances of the outside air. Thus, a large part of the airborne toxins are absorbed. No major maintenance required. Moreover, it is during the winter that calls are more frequent to help the plants grow in the face of more difficult situations[54].

Figure 2.14: Smart walls in office environment

[54] Lopes H. Finnish company creates the world's smartest green walls. Yourweather.co.uk | Meteored. https://www.yourweather.co.uk/news/trending/finnish-company-world-s-smartest-green-walls-plants-agriculture.html. Published October 27, 2022.

Location: Espoo, Finland
Client: Siemens
Installation: -
Project Specialist: NAAVA

Siemens' office building is located in the Voltti building of the Derby Business Park in Espoo. They have a Platinum LEED certification and won the title for "Most Comfortable and Energy Efficient Building in Finland 2014" organized by the Green Building Council Finland. Key factors when building sustainable environments include smart solutions that ensure healthy indoor air, comfortable temperature, and purposeful lighting. A greener indoor environment involves material choices as well as physical and psychological well-being of employees Naava's air purifying green walls complement the focus of Siemens' premises by utilizing technology to purify and humidify indoor air. Naava's furniture-like functionalities are utilized as space dividing elements in Siemens' open offices while also creating areas for breaks and recovery[55].

Figure 2.15: Smart wall at Siemens office in Helsinki, Finland

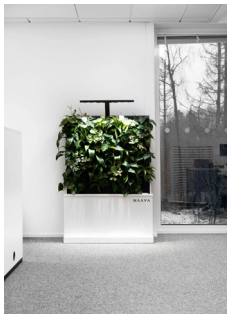

Figure 2.16: Small Smart wall in Siemens office in Helsinki, Finland

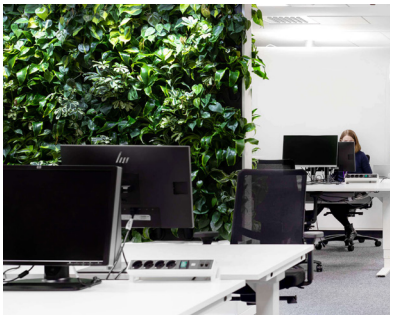

Figure 2.17: Near shot of Smart wall at Siemens office in Helsinki, Finland

[55] Siemens. https://www.naava.io/en/references/siemens

Artificial System:

The use of synthetic living walls, also known as artificial green walls, has become increasingly popular as a customizable and low-maintenance alternative to real plant walls. These fabricated green walls are assembled using a mixture of artificial plants, flowers, foliage, and imitation ivies. These artificial green walls are designed to mimic the natural beauty of live plants, with realistic colors, textures, and dimensions. They provide an option for introducing greenery into spaces where live plants may not thrive, such as areas with low light or limited access to water[56]. Their maintenance-free design makes them suitable for diverse spaces providing options for purchase through multiple retailers to serve different purposes like decor or privacy screens indoors.

Figure 2.18: Artificial green wall at IPIC Theater

[56] Vistafolia The Home Of Artificial Living Walls. Foliage Wall: Vistafolia® Artificial Green Wall.; 2024. https://vistafolia.com/gb/product/vistafolia-artificial-green-wall-panels/

Location: London, UK
Client: The RSBC Headquarters
Installation: -
Project Specialist: Vistafolia

The building on the River Thames has been designed to be functional for staff and provide help and support for blind and partially sighted children. The combination of artificial plant wall panels and bright, striking artwork has been carefully chosen to create an interesting and enjoyable environment. Each artificial plant has been meticulously designed by hand to mimic natural shapes and colors, resulting in an authentic look once installed. The design of the layout is distinctive and avoids redundancy, resulting in a seamless appearance. The selection of Color and Texture Boxes offers a range of foliage that enriches the green wall's verdant and realistic appearance[57].

Figure 2.19: Artificial green wall at RSBC headquarters in London

[57] Vistafolia The Home Of Artificial Living Walls. The RSBC Headquarters, London - Vistafolia.; 2024. https://vistafolia.com/gb/case-studies/the-rsbc-headquarters-london/

Mobile System:

Mobile green walls introduces a groundbreaking method in contemporary indoor environments, especially in versatile settings such as offices and homes. These adaptable structures provide a wide range of advantages that align with modern design concepts and environmental awareness. This system bring exceptional adaptability to interior design, allowing easy adjustment of space and customization of surroundings based on evolving requirements or personal preferences. This flexibility is particularly valuable in open-plan spaces that often require layout changes[58].

Figure 2.20: Mobile Green Walls

Figure 2.21: Mobile Green Walls at lunch area

[58] Mobile green walls - the advantages of mobile office furniture. (n.d.). https://4naturesystem.com/en/blog/bid-196-mobile-green-walls-the-advantages-of-mobile-office-furniture

Location: Utrecht, the Netherlands
Client: -
Installation: -
Project Specialist: Maxgreenwall

The office features tall ceilings and numerous windows, which contribute to the high noise levels. Excessive workplace noise can be a major disruption and have an impact on productivity. The installation of mobile walls has effectively lowered the background noise and greatly enhanced the overall sound quality within the office space, creating a more enjoyable working environment[59].

Figure 2.22: Mobile Green Wall in the entrance of the office in Ultrecht

Figure 2.23: Mobile Green Wall in the office in Ultrecht

[59] Maxgreenwall produkte - Maxgreenwall. Maxgreenwall. Published October 6, 2022. https://maxgreenwall.de/product/maxgreenwall-produkte/

Magnetic Systems:

Magnetic green walls represent a contemporary and inventive method for establishing green walls. These systems make use of strong magnets to affix modular planters or pots to a magnetic base, enabling effortless customization and reorganization of the vegetation.

The magnetized characteristic offers adaptability in arranging the plants, rendering it a convenient and flexible solution for integrating greenery into indoor environments. These planters can be affixed to steel chalkboards or other magnetic surfaces, facilitating the creation of easily maintainable and customizable modular green walls down to each specific detail[60].

Two companies, Kalamitica and Lechuza, have emerged as leaders in the development of magnetic green wall systems for integrating plant life into interior spaces. These innovative systems offer flexible and space-saving solutions for incorporating greenery into any environment. While specific project examples are limited online, Lechuza's Green Wall Home Kit Color provides a practical solution for creating individual herb gardens using magnetic holders to attach pots to metal strips on walls.

Figure 2.24: Magnetic Green Wall by Lechuza in the kitchen

[60] Kalamitica by Sgaravatti Trend Srl. Creating an easy-to-maintain indoor green wall, a guide. Kalamitica by Sgaravatti Trend Srl. https://kalamitica.com/en/content/62-blogcon-creating-an-easy-to-maintain-indoor-green-wall-complete-guide#parete6

Location: Utrecht, the Netherlands
Client: -
Installation: -
Project Specialist: Maxgreenwall

This system not only ensures a secure hold with strong magnets but also adds stylish design accents through its satin colors and finely crafted structure, allowing users to transform small kitchens into hubs for fresh herbs[61].

On the other hand, Kalamitica offers a customizable magnetic system with steel chalkboards and cachepots in various shapes, colors, and sizes designed for easy maintenance without disrupting surrounding cleanliness.

The inclusion of permanent neodymium magnets ensures plant stability while offering a wide range of minimalist black-and-white accessories designed to enhance contemporary environments[62]. Although direct examples of projects utilizing these magnetic green wall systems are not readily found online, their innovative features highlight the potential of these systems in transforming indoor spaces by effectively incorporating nature into homes and offices in an aesthetically pleasing manner.

Figure 2.25: Magnetic Green Wall by Kalamitica in the office environment

[61] LECHUZA Self-Watering Planters - USA. https://www.lechuza.us/home/

[62] Kalamitica by Sgaravatti Trend Srl. Creating an easy-to-maintain indoor green wall, a guide. Kalamitica by Sgaravatti Trend Srl. https://kalamitica.com/en/content/62-blogcon-creating-an-easy-to-maintain-indoor-green-wall-complete-guide#parete6

The Fytotextile System:

The patented fytotextile system consists of a modular design with three flexible layers made of both organic and synthetic fabrics, each with reduced thickness. All modules have an upper flange for assembly and inspection of the drip irrigation system. The multilayer modules of Fytotextile enhance plant health by having a high transpiration capacity in the outer layer and creating an optimal balance between water, air, and substrate in the submerged part of the plant[63].

Figure 2.26: Components of a Fytotextile Living Wall

[63] TERAPIA URBANA. FYTOTEXTILE® LIVING WALL . Published July 17, 2023. https://terapiaurbana.es/en/fytotextile-living-wall/

Location: San Francisco, USA
Client: 14th Street Studio
Installation: -
Project Specialist: PlantsOnWalls

The designers used the innovative Fytotextile system by PlantsOnWalls to create a lush, jungle-like space in a private live/work studio on San Francisco's 14th Street. This involved attaching air-gap wall spacers to the existing concrete surfaces of the studio and then installing Floraframe edge channels, a waterproof vapor barrier, and Florafelt vertical garden planters. This approach seamlessly integrated rich greenery into the studio environment while also ensuring structural integrity of the wall and plant health through efficient water management and air circulation. The adaptability and ease of installation of this system make it an excellent choice for enhancing both aesthetics and ecological value in workspace design[64].

Figure 2.27: Fytotextile Green Wall in a private live/work studio in San Francisco

[64] Systems FLW. 14th Street Studio — Florafelt Living Wall Systems. Florafelt Living Wall Systems. Published February 4, 2024. https://florafelt.com/plantson-walls/2011/07/14th-street-studio.html

Panel/Modular System:

Panel green wall systems have gained significant popularity among consumers due to their adaptability for use in both outdoor and indoor environments, regardless of the climate. These systems offer a diverse range of design options and can accommodate plants with different watering requirements. They are well-suited for creating brand-specific displays and personalized designs. The panels are pre-populated with a variety of plants at a nursery before being vertically installed onto a support framework.

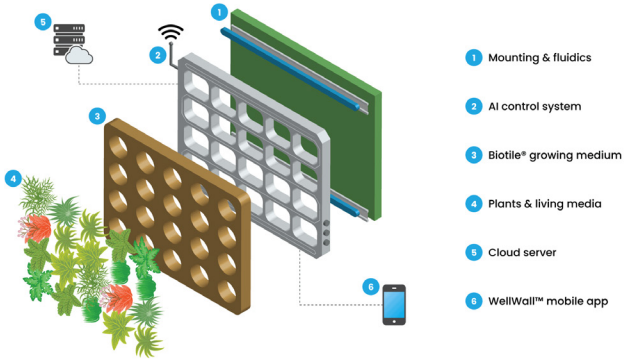

Figure 2.28: Components of a Panel/Modular Living Wall System

Typically consisting of modular panels, boxes, or cassettes designed to hold various growth media, these systems enable the installation of fully grown and densely arranged plants. In addition to their aesthetic appeal, panel green wall systems align well with environmental efforts as they provide advanced irrigation solutions such as gray water compatibility or water re-circulation. Furthermore, implementing these systems may contribute towards earning LEED credits through their incorporation of recycled content, local production practices, and efficient water usage in landscaping initiatives[65].

[65] Ambius' Green Wall Solutions: Transforming Your Spaces. Rentokil Initial. https://www.ambius.com/plant-design/green-walls/systemshttps://planterra.com/services-3/living-walls/

Location: Cardiff, UK
Client: ISG
Installation: 2023
Project Specialist: Biotecture

Biotecture design and project management team oversaw the integration of the living wall into Legal and General's new flagship HQ. The hydroponic living walls were pre-grown at a Biotecture patented BioPanel modular panels dedicated nursery facility in West Sussex before being installed on site. Installation included two phases: first fix involved backing board installation and commissioning of irrigation system; second fix entailed planted panel installation between aluminum mounting rails using a BMU system located above for ongoing maintenance. An integrated irrigation system was remotely monitored from the head office to ensure proper plant care[66].

Figure 2.29: Legal & General Wales HQ Reception Living Wall

[66] Legal & General Wales HQ Reception Living Wall - Biotecture. Published November 27, 2023. https://www.biotecture.uk.com/portfolio/legal-general-wales-hq-reception-living-wall/

Tray Systems:

Tray systems for green walls are well-suited to indoor spaces like building lobbies, reception areas, and places with high foot traffic. They can cover an entire wall or be arranged as a framed living artwork. These systems are particularly convenient for dynamic organizations as they do not require plant pre-growth before installation, allowing for quick setup. Utilizing a backing board, trays can be stacked in customized configurations while keeping the plants in their nursery pots at a slight angle within the trays. Irrigation options include holding tanks or direct plumbing. The versatility of these systems allows for modular designs, easy plant replacements, adapting to seasonal changes, and temporary installations[67].

Figure 2.30: Tray System by GSky

[67] Ambius' Green Wall Solutions: Transforming Your Spaces. Rentokil Initial. https://www.ambius.com/plant-design/green-walls/systems

Location: OVERLAND PARK, KS
Client: Shawnee Mission School District
Installation: 2017
Project Specialist: Gsky

The Center for Academic Achievement at Shawnee Mission School District is known for its modern design, which includes a unique two-story living wall. This living wall aligns with the building's focus on sustainability and academic excellence, using a tray system to improve air quality and enhance aesthetics.

Built according to LEED Silver standards, the center prioritizes natural lighting, recycled materials, and an open layout that encourages interaction between staff and students. The living wall not only demonstrates the center's innovative approach to meeting the needs of advanced education but also serves as an interactive educational tool that promotes environmental consciousness and collaborative learning within its architecturally enriching space[68].

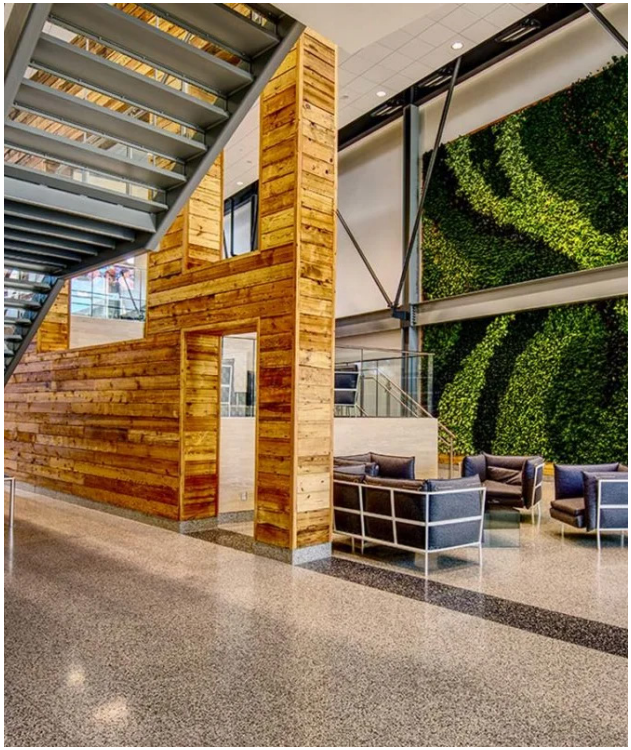

Figure 2.31: Tray System Green Wall by GSky in Shawnee Mission School District

[68] Center for Academic Achievement – ACI Boland. https://www.aciboland.com/portfolio/center-for-academic-achievement/

Grid-Frame Systems:

Constructing a green wall involves installing a grid frame onto the designated wall, typically made of metal or recycled plastic. This framework has modular cells for planting and can accommodate different types of plant modules[69]. The selection of plants considers local climate and design preferences, while an irrigation system supports plant growth. As the plants thrive, they cover the grid frame and transform it into a flourishing green wall. Regular maintenance includes routine inspections, pruning when necessary, and replacing plants as needed to ensure continued vitality.

Figure 2.32: Vertical Garden Grid Frame System by Joost Bakker

[69] Frenchams. Office Grid Frame Green Wall Systems -https://www.frenchams.com.au/range/grid-frame-green-walls/

Location: Sydney, Australia
Client: Macquarie University's
Installation: -
Project Specialist: Schiavello

Schiavello's Vertical Gardens, used in a grid frame system, transformed the division of space within a student environment without requiring permanent structural changes. Architectus chose modular barriers to create distinct areas while avoiding the permanence and expense of construction, promoting enclosure, color, and materiality. This approach allowed for immersive spaces that encourage comfort and focus while maintaining flexibility. Integrating living semi-transparent walls with plants enhanced aesthetic appeal and utilized biophilic design principles to enhance students' health, well-being, and performance. The popularity of these green walls among students underscores their effectiveness in creating inviting and productive environments[70].

Figure 2.33: Schiavello's Vertical Gardens are used as modular barriers to create a sense of enclosure, colour and materiality.

[70] Schiavello. Macquarie University. Schiavello Furniture. Published May 24, 2019. https://www.schiavello.com/furniture/projects/Macquarie-University

ADVANTAGES AND DISADVANTAGES

A comparative analysis of available green wall systems in the market has been created. This analysis evaluates the pros and cons of each system, offering a comprehensive framework for architects, designers, and environmental scientists interested in integrating green walls into indoor environments.

Mobile systems are notable for their self-contained design and adaptable positioning, making them effective in acting as dynamic room dividers in open-plan spaces. However, despite their flexibility, these systems can occupy significant floor space, may lack stability compared to permanent installations, and require consistent maintenance[71].

Grid-Frame Systems are sturdy and easy to install and maintain. They also offer mobility and portability. However, they have limited space for root growth which may result in a more uniform appearance. Larger installations could involve substantial expenses[72].

Trellis Systems offer support for various climbing plants and present a cost-effective option compared to other systems, with minimal upkeep requirements. However, they are limited to plant species capable of climbing, may require a considerable amount of time to achieve full coverage, and might necessitate additional support structures[73].

[71] Mobile green walls - the advantages of mobile office furniture. https://4naturesystem.com/en/blog/bid-196-mobile-green-walls-the-advantages-of-mobile-office-furniture

[72] Frenchams. Office Grid Frame Green Wall Systems -https://www.frenchams.com.au/range/grid-frame-green-walls/

[73] Sharp D. Trellis green walls vs pocket based green walls. Green Walls. Published April 12, 2021. https://green-walls.co.uk/blog/trellis-green-walls-vs-pocket-based-green-walls/

Artificial systems are known for their low maintenance and durable visual appeal, making them a practical choice for dimly lit spaces and cost-effective in the long run. However, they lack the ecological and health advantages of live plants, may not have as natural an appearance, and are often made from non-environmentally friendly materials[74].

Moss Walls provide advantages in regulating indoor humidity and require minimal upkeep, making them long-lasting. They can be adapted to various spaces and shapes, but the costs of installation can be high when scaled up[75].

Magnetic systems are known for their ability to be easily customized and for the flexibility in arranging plants. However, they have limitations on weight which restricts the size of supported plants, and using high-quality magnets can increase expenses. Additionally, insufficient anchoring may lead to potential slippagerisks[76].

Smart Wall Systems represent the fusion of technology with eco-friendly wall design, incorporating automated and monitored maintenance systems to enhance air quality while demanding minimal maintenance. The considerable upfront cost of implementing such advanced features is accompanied by a dependency on the sustained operation of the technological systems, which may necessitate specialized skills[77].

POD Plant Systems provide flexibility by being able to be installed on uneven surfaces with an uncomplicated irrigation system and easy installation process. However, the range of plants that can be accommodated may be restricted due to limitations in pot size[78].

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[74] Woods, R. (n.d.). Pros and cons of artificial plant walls. https://www.evergreenwalls.com.au/blog/pros-and-cons-of-artificial-plant-walls

[75] Walls E. 10 scientific benefits of moss walls. https://www.evergreenwalls.com.au/blog/green-walls-2/10-scientific-benefits-moss-walls

[76] Kalamitica by Sgaravatti Trend Srl. Creating an easy-to-maintain indoor green wall, a guide. Kalamitica by Sgaravatti Trend Srl. https://kalamitica.com/en/content/62-blogcon-creating-an-easy-to-maintain-indoor-green-wall-complete-guide

[77] Naava. What are Green Walls - the Definition, Benefits, Design, and Greenery. Published July 24, 2017. https://www.naava.io/editorial/what-are-green-walls

[78] POD Living Plant Wall System | Green Oasis. Green Oasis. Published December 28, 2023. https://greenoasis.com/living-walls/pod-living-plant-wall-system/

Tray Systems are recognized for their simplicity, which results in cost savings and allows for plants to be easily relocated for better light exposure. Despite these benefits, there is a higher initial cost involved and a possibility of the irrigation system getting clogged over time[79].

Fytotextile Systems support optimal plant growth and offer a lightweight and flexible solution, suitable for various uses while being customizable to suit specific project needs. However, they require regular watering and upkeep, posing the risk of water damage and potential deterioration of the felt material over time[80].

Panel/Modular Systems enable the easy removal of planted tiles for convenient maintenance and accommodate a diverse range of plant types. They are flexible in terms of growth media. Nevertheless, potential issues such as problematic drip irrigation, high system maintenance needs, and substrate dislodgment over time should be taken into account[81].

This in-depth examination serves as a critical tool for making knowledgeable choices when designing and implementing green wall systems in interior environments. It emphasizes the significance of a thorough selection process that considers the visual, ecological, and practical aspects unique to each project.

[79] Ambius' Green Wall Solutions: Transforming Your Spaces. Rentokil Initial. https://www.ambius.com/plant-design/green-walls/systems

[80] Fytotextile Living Wall - not just a "felt" system. Scotscape. https://www.scotscape.co.uk/blog/fytotextile-living-wall-felt-system

[81] Fojtíčková M. What are the systems for building green walls? Flora Urbanica. Published March 22, 2021. https://floraurbanica.com/en/what-are-the-systems-for-building-green-walls/

GREEEN WALL SYSTEMS	ADVANTAGES	DISADVANTAGES
Mobile System 	• Self-contained irrigation • Versatile placement options • Maximum flexibility • Acts as space separation in the open space	• Can occupy valuable floor space • Potentially less stable • Regular maintenance requirement
Grid-Frame System 	• Stable and durable • Easy to install and maintain • Movable and portable	• Restricted root growth space • More uniform appearance • Can be expensive for larger installations
Trellis System 	• Supports a variety of climbing plants • Economical compared to other systems • Low-maintenance option	• Limited to suitable climbing plants • Takes time for full coverage • May require additional structural support
Artificial System 	• No maintenance required • Long-lasting appearance • Suitable for low-light areas • Cost Effective	• Does not provide the benefits of live plants • May not look as natural • Often made from less eco-friendly materials
Moss Wall 	• Help to stabilise humidity • Maintenance-free and long-lasting • Suitable for a variety of spaces and shapes	• Can be costly to install on a large scale
Magnetic System 	• Easy customization and reconfiguration • Flexible plant arrangement	• Weight limitations for plant support • Potential for slippage if not secured • Possible higher cost due to magnet quality
Smart Wall System 	• Automated and monitored maintenance systems • Optimized air humidity, and air biofiltration. • Minimal maintenance required	• High initial investment and operating costs • Technical complexity may require expertise • Reliance on technology for system function
POD System 	• Extend plant life • Can be installed irregular surfaces • Simple irrigation • Easy to install	• Plant variety may be limited due to pot size
Tray System 	• Plants are easily replaceable • Short lead time • No plant pre-growth period • Relatively simple system, resulting in cost savings	• Initial investment costs are higher • Possible clogging over time
Fytotextile System 	• Supports excellent plant health • Lightweight and versatile for various applications • Can be customized for specific project needs	• Requires regular watering and maintenance • Potential for water damage • Felt may degrade over time
Panel /Modular System 	• Planted tiles are easily removed for easy access to irrigation lines • Very forgiving growth media • Supports a diversified plant palette	• Problematic drip irrigation • High maintenance of the system • The substrate falls out of the baskets over time

Table 2: Advantages and Disadvantages of Green Wall Systems

CATEGORIZATION OF THE SYSTEMS

This categorization is grounded in the spatial aspect of interior design. The table is intended to clarify the importance and role of green wall systems in interior design, going beyond their decorative purpose to address specific spatial considerations and needs within interiors.

By grasping these categorizations, designers and architects can more effectively utilize green wall systems to enhance spatial arrangements within interior designs. Therefore, this table has been created to emphasize the significance of fully utilizing the potential of green walls as transformative elements that enhance interiors cohesively, functionally, and aesthetically.

This study has established five fundamental typologies for understanding and classifying green wall systems used in interior environments. These classifications are founded on the functions of green walls and the requirements of the spaces where they are implemented. Each classification encompasses distinct green wall systems alongside thorough justifications for their integration.

Spatial Dividers and Privacy Screens:

In today's modern office setting, green walls are used as both spatial dividers and privacy screens to separate open areas, establish private spaces, and define individual work zones. These living walls serve a dual purpose by offering the necessary privacy for focus and confidential conversations while also adding natural vitality to the workspace. By incorporating these systems, the functionality of the office layout is improved, allowing for the creation of semi-permeable boundaries that encourage collaboration without compromising personal workspaces. The integration of nature into space division with these green walls contributes to a healthier and more welcoming office environment, promoting well-being and productivity among employees.

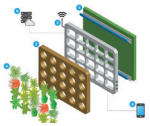
TYPOLOGY	SYSTEM	DESCRIPTION
Spatial Dividers and Privacy Screens	 Trellis System  Mobile System  Grid-Frame System	This typology aims to create personal spaces for individuals in open areas within indoor environments. The goal is to transform the open space into airy and spacious private rooms.
Aesthetic Focus Point and Feature Walls	 Artificial System  Moss Wall	This typology aims to create decorative green walls that create visual impact on living spaces. They bring nature indoors and offer a consistent aesthetic.
Innovative Spatial Solutions	 Smart System  Magnetic System	Technologically advanced green walls that are interactive and flexible. Smart walls for modern, eco-conscious spaces, and magnetic systems for personalization.
Solutions for Limited Spaces	 POD System  Tray System	Versatile and adaptable green walls suitable for small or constrained areas, adding a touch of greenery in a practical manner.
Functional and Practical Applications	 Fytotextile System  Panel/Modular System	This typology is centered on green wall systems known for their operational functionality and practicality.

Table 2.1: Categorization of the Green Wall systems

Aesthetic Focal Point and Feature Walls:

The classification includes Moss Walls and Artificial Systems, which act as important decorative components in indoor areas. These green walls are specifically created to make a powerful visual impression, connecting living spaces with elements of nature and artistic expression. Moss Walls bring natural beauty indoors, providing a vibrant and calming living artwork that can inspire inhabitants. Their lush appearance adds depth to the environment, enhancing the overall sensory experience. In contrast, Artificial Systems offer a consistent and always-green aesthetic, suitable for spaces with limited natural light or restricted maintenance capabilities. Both systems are designed to function as centerpieces that not only attract attention but also subtly shape the character and atmosphere of a room while promoting the integration of nature within human habitats.

Innovative Spatial Solutions:

This typology integrates Smart and Magnetic green walls, embodying advanced, interactive technology for modern interiors. Smart walls, equipped with self-regulating systems, are designed for eco-conscious spaces, automatically adapting to environmental needs. Magnetic walls offer unparalleled personalization, allowing flexible arrangement of plant modules for dynamic and customizable green spaces. Together, these systems represent the intersection of technology and nature, offering adaptive and engaging green solutions in contemporary design.

Solutions for limited spaces:

This typology, featuring Potted Plant (POD) and Tray Systems, provides versatile and adaptable green wall options ideal for compact or constrained environments. Potted Plant systems offer the flexibility to introduce greenery in varied spatial configurations, making them suitable for areas where traditional green walls may not be feasible. Tray Systems complement this by allowing for modular installations that can be customized to fit unique spatial limitations. Both systems are designed to bring a practical and aesthetically pleasing touch of nature to smaller spaces, enhancing the environment without the need for extensive structural modifications.

Practical Applications:

This typology includes Fytotextile and Panel Modular Green Wall Systems, recognized for their efficient operation. Fytotextile Systems present a versatile green wall solution with their lightweight construction and hydroponic features, making them suitable for various indoor environments while promoting optimal plant health. Complementing this, the Panel Modular Systems offer a flexible and easy-to-configure option that can adapt to space limitations while maintaining visual appeal. Together, these systems represent a practicality designed to meet the needs of contemporary architecture and interior design through emphasis on usability and sustainable living practices.

WELL-BEING FRAMEWORK ON SYSTEM TYPOLOGIES

A study has been conducted in this section regarding the necessary considerations for promoting well-being when incorporating green walls into indoor environments. The integration of green walls in interior design can significantly contribute to well-being by addressing various requirements as identified in the framework[82] . The well-being framework for interiors aims to define the spatial dimensions of well-being in order to evaluate the importance of every spatial aspect that impacts our interior-related well-being. The framework's structure is informed by emotional, contextual, functional, psychological, social, sensory, aesthetic and ergonomic requirements that are interconnected[83].

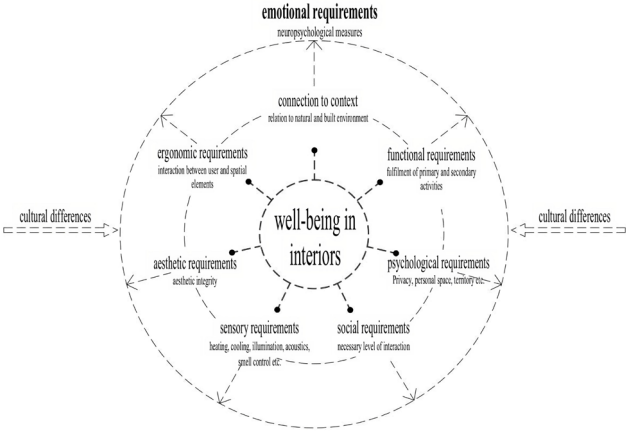


Figure 2.34: The updated Well-being Framework for Interiors

[82] Minucciani, V., Saglar Onay, N. Rethinking the well-being framework in the current scenario, Environments By Design: Health, Well-being And Place, AMPS, Virtual Conference, 1-3 December, 2021

[83] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

Contextual Requirement:

Contextual requirements ensure that the interior space is in harmony with its external surroundings, taking into account factors such as cultural context and geographical location.These focus on the unique characteristics of the environment, including its location and relationship to the surrounding world[84].

Green walls help to connect interior spaces with the outdoors, re-establishing a link with nature that is frequently absent in urban environments. Incorporating natural elements into built structures allows green walls to mirror the location and cultural background of a space, encouragingunity between the interior and exterior surroundings. This biophilic design concept improves individuals' feelings of attachment and relationship with their environment.

Functional Requirement:

Functional requirements ensure that the design of the living environment facilitates daily tasks and activities, promoting efficiency and ease of use. These are concerned with creating spatial solutions that support human activities[85].

Green walls address functional requirements by optimizing air quality, regulating temperature, and enhancing acoustics, thereby improving the usability and comfort of spaces. They contribute to efficient spatial layouts and adaptable environments, supporting the diverse activities and needs of users while enhancing the overall functionality and quality of life within interior spaces.

[84] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

[85] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

Psychological Requirement:

Psychological requirements consider the impact of the environment on human emotions, behavior, and cognitive processes, aiming to create spaces that promote positive psychological outcomes. These address the emotional and mental well-being of individuals within the space[86].

The inclusion of living walls in indoor environments has been found to have beneficial impacts on mental well-being, including stress reduction, mood enhancement, and cognitive improvement. Green walls can establish a tranquil atmosphere that promotes relaxation and overall mental health. Furthermore, the visual link to nature may alleviate mental exhaustion and support an environment that stimulates creativity and focus.

Social Requirement:

Social requirements ensure that the design of the environment encourages social connections, collaboration, and a sense of belonging among individuals. These focus on the spatial opportunities for social interaction and community engagement[87].

Green walls can create inviting spaces that encourage social interaction and community engagement. They serve as focal points in communal areas, promoting gatherings and conversations among individuals. This fosters social connections and strengthens the sense of belonging and community within the space, contributing to the social well-being of its occupants.

[86] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

[87] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

Sensory Requirement:

Sensory requirements address factors such as lighting, acoustics, temperature, and other sensory inputs to create a comfortable and stimulating environment for occupants.These consider the impact of sensory stimuli on human experiences within the environment[88].

Green walls contribute to addressing sensory needs in interior spaces by introducing a dynamic and multi-sensory aspect. They can enhance air quality, influence acoustics by reducing noise, and provide an ever-changing visual appeal that breaks the monotony of urban interiors. Additionally, plants can assist in regulating humidity levels for a more comfortable sensory experience.

Aesthetic Requirement:

Aesthetic requirements focus on the harmony, beauty, and visual coherence of the design elements to create a pleasing and inspiring environment that enhances well-being. Aesthetic requirements focus on the harmony, beauty, and visual coherence of the design elements to create a pleasing and inspiring environment that enhances well-being[89].

The visual appeal of green walls is undeniable. They offer a vibrant palette of greens and other colors, depending on the plant selection, that can enhance the aesthetic satisfaction of any space. The design and arrangement of plants can be tailored to complement the architectural elements of the interior, contributing to the visual and sensory coherence of the environment.

[88] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

[89] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

Ergonomic Requirements:

Ergonomic requirements ensure that the design of the space is physically comfortable, safe, and supportive of human health and well-being, considering factors such as posture, movement, and accessibility.These refer to the relationship between the interior components and the human body[90].

Green walls can improve ergonomic well-being by creating physically comfortable and psychologically uplifting spaces. They have the potential to enhance the perceived environmental quality of an area, making it feel more pleasant and conducive to overall well-being. Additionally, the presence of mobile greenery can promote movement and social interaction within a space, contributing to ergonomic health through increased physical activity and decreased sedentary behavior.

[90] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

Emotional Requirement:

Emotional Requirement is understanding the connection between the brain, surroundings, and behavior is crucial in both design and neuroscience. Examining emotional reactions to physical spaces provides valuable insight into how constructed environments impact human emotions, thinking processes, and actions. This perspective enhances comprehension of the complex interrelationships among the brain, surroundings, and behavior. Considering emotional responses to physical spaces allows designers to create environments that promote emotional well-being, enhance cognitive performance, and encourage positive behavior. This enhances the design process and aids in creating settings that positively impact individuals' lives[91].

Green walls directly contribute to fulfilling emotional requirements by fostering an emotional connection with nature. This connection can evoke positive emotional responses, such as happiness and tranquility, enhancing emotional wellbeing. The presence of green walls can also serve as a reminder of the natural world, offering emotional comfort and reducing feelings of confinement or stress in urban settings.

[91] Minucciani, V., Saglar Onay, N. Well-being design and frameworks for interior space. Pennsylvania: IGI Global, 2020

TYPOLOGY / REQUIREMENTS	Spatial Dividers and Privacy Screens	Aesthetic Focus Point and Feature Walls	Innovative Spatial Solutions	Solutions for Limited Spaces	Practical Applications
Emotional	Provides emotional privacy/safety in open spaces by creating private spaces	Positively influence mood and emotions through visual appeal	Stimulates positive emotions through interactive features	Improves mood in confined areas	Reduces stress by increasing comfort
Contextual	Distinguishes areas without making permanent structural alterations	Delivers visually striking environments that connect with inhabitants	Adapts to evolving spatial requirements through flexibility	Maximizes limited space by integrating natural elements	Enhances the bond with nature, promoting biophilia
Functional	Serve practical functions such as establishing and creating private spaces and noise insulation	Maintenance-free solutions that enhance functionality while minimizing effort	Offer advanced functionalities such as interactive features	Act as air purification in compact spaces	Ease of plant management by using a modular approach
Psychological	Provide mental comfort by creating a sense of personal space and security.	Enhances mental wellness through the enjoyment of visual stimuli	Promote creativity and mental engagement through innovative designs.	Reduces the sensation of being crowded and enhances the feeling of spaciousness	Enhances cognitive function by improving air quality.
Social	Facilitates social interaction by defining semi-private spaces	Acts as a social catalyst, sparking discussion and sharing of experiences	Encourage socialization and collaboration through interactive and communal features.	May improve ambiance, encouraging casual socialization	May enhance communal well-being by creating a healthier environment
Sensory	Screens can act as sound barriers, improving acoustics	Offers a visual sense of texture and the potential for tactile perception	Smart systems modulate environ-mental conditions, magnetic interac-tions stimulate tactile engagement	Enhances visual and olfactory senses	Improves air purification, humidity control, and temperature regulation
Aesthetic	Adds visual and tactile texture to spaces	Serve as a key visual element, significantly enhancing the interior's aesthetic value.	Enhances dynamic visual experience	Brings visual interest and nature into small areas	Adds plant life, enhancing the visual attractiveness
Ergonomic	Ergonomically shapes and personalizes spaces	Maintenance-free, reducing physical effort	Adapt to user needs, ensuring comfort and ease of interaction.	Designed for efficiency and comfort in small-scale environments.	Aligns with human comfort needs, ease of maintenance

Table 2.2: Green Wall Typologies analysis by Well-being requirements for interior design

The table presented illustrates a comprehensive correlation between different green wall typologies and a wide range of well-being requirements in the field of interior design. Each typology goes beyond its primary function and interacts with multiple aspects of human well-being, highlighting the multifunctional nature and central role of green walls in creating balance within interior habitats.

Spatial Dividers and Privacy Screens:
These structures are a testament to the multifaceted role of green walls, which not only address the need for emotional and social well-being by providing security and privacy, but also address functional, psychological and sensory needs by increasing spatial efficiency and mental ease.

Aesthetic Focus Point and Feature Walls:
This typology, consisting of non-living plants, does not embody natural effects in the traditional sense. Instead, it offers an aesthetic enhancement through the use of moss and artificial walls, providing visual interest and design cohesion in spaces. While these elements are not derived from living plants, they still contribute to well-being by creating a visually appealing environment that can stimulate mental relaxation and psychological comfort, thereby indirectly enhancing quality of life.

Innovative Spatial Solutions:
This typology represents a holistic approach to spatial design, integrating innovative solutions that cater to a wide range of human needs and preferences. By stimulating positive emotions and adapting to changing spatial requirements, these designs prioritize flexibility and functionality through interactive features. They foster creativity and mental engagement with their innovative designs, promoting social interaction and collaboration via communal spaces and interactive elements. Additionally, sensory engagement is elevated through smart systems that modulate environmental conditions and magnetic interactions, enhancing tactile experiences. The dynamic visual appeal is amplified, ensuring that aesthetics are not overlooked, while ergonomic considerations guarantee comfort and ease of interaction for users.

Solutions for limited spaces:
This typology offers solutions designed for limited spaces, focusing on improving the quality of life within confined areas. By integrating natural elements and maximizing available space, these solutions provide a comprehensive approach to managing space. Functional benefits include air purification for a healthier living environment, while psychological strategies reduce feelings of crowding and create an illusion of spaciousness. The improved ambiance fosters casual interactions and enriches the social fabric of the space. Visual and olfactory enhancements heighten sensory experiences, bringing a sense of nature and openness into small areas. These solutions also add visual interest aesthetically, making compact spaces more inviting and pleasant. They are ergonomically designed to optimize efficiency and comfort so that even the most limited spaces can be transformed into functional, enjoyable environments.

Practical Applications:
This typology emphasizes practical applications to enhance the environment and well-being by integrating plant elements, fostering comfortable and soothing atmosphere. It strengthens our connection to nature by advocating for principles that underscore the importance of human-nature interactions. Functionally, it introduces a modular approach to plant management for simplified care and maintenance, contributing to improved air quality linked to enhanced cognitive functions in productive spaces while aiding communal well-being.

This studuy has meticulously investigated the interrelation between green wall typologies and well-being requirements within interior design. Utilizing the well-being framework developed by Nilüfer Sağlar Onay and Valeria Minucciani, the study has elucidated how each typology contributes to various dimensions of well-being. The findings indicate that green walls possess the potential to enhance aesthetic, functional, emotional, and social aspects of a space. Furthermore, it is evident that green walls also exert positive influences on psychological and ergonomic well-being.

DESIGN SOLUTIONS

In exploring design solutions for green walls in interior spaces, it is important to revisit the essence of integrating nature within our built environments. The incorporation of green walls goes beyond aesthetic enhancement and embodies a multifaceted strategy for addressing environmental, psychological, and social challenges in modern urban living.

Green walls represent a harmonious blend of aesthetics and functionality, offering tangible benefits that extend well beyond their immediate visual appeal. They embody a forward-thinking approach to design that prioritizes sustainability, well-being, and connectivity. The following sections will explore innovative design strategies that not only optimize these benefits but also address the inherent challenges of integrating green walls into diverse interior spaces with the aim of underscoring their indispensable role in crafting resilient, healthful, and vibrant indoor environments for the future.

Life Cycle Assessment

It is commonly employed to assess the effectiveness of a system post its design and construction. When utilized during the design phase and material selection, LCA serves as a valuable tool for making decisions that reduce the environmental impact of a system. Integrating LCA into the design phase of green wall systems can greatly enhance their environmental performance and is imperative for their long-term sustainability. This approach provides valuable insights into minimizing environmental impacts in system components, enabling identification of significant areas of impact and strategies for mitigation. Therefore, LCA holds crucial significance as a decision-making tool during the design processes of these systems[92].

[92] Reyhani M, Santolini E, Tassinari P, Torreggiani D. Environmental assessment of design choices of green walls based for materials combination and plants. The International Journal of Life Cycle Assessment. 2023;28(9):1078-1091. DOI:10.1007/S11367-023-02181-X

Integrating AI and Smart Technology for Maintenance and Longevity

With the increase in urbanization, it is crucial to incorporate natural elements into constructed areas to minimize environmental effects and improve well-being. Green walls installed on indoor walls provide a promising approach by aiding in air purification, promoting well-being, regulating temperature, and enhancing visual appeal. Nonetheless, their widespread use encounters difficulties such as upkeep costs due to maintenance and the need for specialized expertise. Artificial Intelligence can offer potential solutions for addressing these challenges and prolonging the longevity of indoor green walls.

One of the key advancements brought by AI in green walls is the ability to monitor the maintenance and health of the plants. Utilizing sensors and IoT (Internet of Things) technology, AI systems can consistently oversee plant health, soil moisture levels, nutrient requirements, and overall wall condition.

By examining this information, AI can forecast plant distress or illness before it becomes visible, allowing proactive measures to preserve plant well-being. This may involve modifying water distribution to specific areas or providing focused nutrients to distressed plants. Such precise maintenance has the potential to greatly decrease labor costs and resource waste, enhancing the longevity of green walls.

AI can play a significant role in enhancing the environmental advantages of green walls, going beyond basic maintenance. By monitoring factors like indoor air quality, humidity levels, and oxygen production, AI systems can offer valuable insights into the performance of green walls. This data may be used to advise building managers or occupants on when optimal ventilation is needed or whether additional air purification is necessary, thereby improving the effectiveness of green walls in enhancing indoor environmental quality.

The incorporation of AI changes green walls from static natural features into dynamic components within interior spaces. Through AI technology, green walls can adapt to environmental variations and occupant requirements, creating a more interactive relationship between nature and technology.

For instance, AI could regulate the lighting surrounding green walls to support plant growth or enhance their visual appeal based on specific times of day or seasonal changes. Additionally, AI can facilitate educational and engaging experiences for occupants by providing real-time information about the plants and their environmental benefits.

Choosing Right Plant Species

Selecting the right plant species is crucial for ensuring the long-term viability and effectiveness of green walls. It's important to choose plants that are well-suited to the local climate and environmental conditions, as this reduces the need for extra maintenance needs. The careful selection of plant species is a fundamental element of sustainable design, impacting not only aesthetics but also environmental adaptation, biodiversity advantages, resource efficiency, and societal value. Thoughtfully chosen plants can turn green walls into sustainable installations that play a positive role in interiors, improve public health and wellness, and bolster environmental resilience.

Sustainable Materials

When designing a green wall for interior space with a focus on sustainability and eco-friendliness, selecting recycled materials is not just an environmentally responsible choice but also a statement of commitment to the planet. This approach ensures that the green wall contributes positively to the interior environment, both aesthetically and ecologically, by minimizing its carbon footprint and promoting a circular economy.

The structural frame can be crafted from recycled metals such as aluminum or stainless steel, which offer durability and strength. Modular panels or trays made from versatile recycled plastic reduce landfill waste and are ideal candidates due to their resistance to decay. For the growth medium, consider using biodegradable options like coconut coir sourced from sustainable environments or foam made from recycled plastics providing excellent water retention crucial for plant health. The irrigation system incorporating tubing made from recycled plastics minimizes water usage through drip irrigation targeting roots directly and reducing waste efficiently. Waterproof layers are crucial for protecting the interior space & components of the drainage system can use waterproofing material made out of recyclable rubber/plastic. Opting for LED lights & electronics control systems with recycling components enhances energy efficiency. Choosing these sustainable practices promotes well-being in indoor design creating visually stunning environmentally friendly green walls.

CASE STUDIES

The incorporation of green walls into indoor spaces represents a revolutionary strategy for sustainable design, seeking to integrate the advantages of nature into constructed environments. In order to comprehensively examine the impacts of vertical gardens in diverse settings, this section employs a classification method. This categorization is crucial as it acknowledges that the influence of vertical gardens goes beyond visual improvement and encompasses contributions to mental well-being, air quality enhancement, and energy efficiency. However, these benefits can vary significantly based on where they are implemented. By dividing the case studies into four specific categories office and workspaces, educational institutions, communal areas, and residential interiors the goal is to uncover the intricate ways in which vertical gardens interact with each environment. This classification enables targeted exploration into distinct outcomes and benefits realized in each context. For example, in office spaces, there may be an emphasis on productivity and air quality improvement; meanwhile education environments might focus on learning enhancement and well-being. Community areas and residential interiors offer additional opportunities for investigation regarding social cohesion as well as individual health and comfort due to their unique dynamics.

This systematic approach provides a comprehensive understanding of the varied effects of green walls by examining various case studies within these categories showcasing not only their adaptability but also emphasizing how context plays a key role in maximizing potential advantages. This structured analysis forms the basis for promoting wider usage of green walls while offering valuable insights into their significance as fundamental components of sustainable interior design across different contexts.

Green Walls in Office and Working Spaces

Indoor biophilic design is being more widely acknowledged as an effective method for improving cognitive performance, providing necessary respite from work-related stress, and supporting mental and physical health[93]. Exposure to plant life could potentially have a beneficial impact on maintaining focus during both short and prolonged breaks from work, facilitating more effective relaxation of directed attention[94].

Research indicates that 87% of workers desire healthier workspace benefits from their current employer, according to the WELL Building Standard. Plants have a positive impact on individuals, particularly in workplace settings. Research shows that having greenery in offices leads to increased creativity and productivity among employees compared to non-green workplaces. In addition, the introduction of plants also enhances employee engagement and concentration levels. A significant number of office workers operate in open-plan offices where ambient noise is a major source of annoyance, causing issues like decreased focus, frustration, fatigue and headaches. Installing a living wall serves as an effective sound barrier by absorbing more sound than traditional walls and reducing ambient noise by 8 dB[95].

Creating a green environment within workspaces has been found to positively influence the well-being of employees by making them happier, healthier and boosting their energy levels while also promoting relaxation and reducing stress through the presence of plants with bright colors. Implementing indoor living walls has demonstrated reduced sick leave rates and improved employee satisfaction.

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[93] Ma X, Du M, Deng P, Zhou T, Hong B. Effects of green walls on thermal perception and cognitive performance: An indoor study. Building and Environment. 2024;250:111180. doi:10.1016/J.BUILDENV.2024.111180

[94] Raanaas RK, Evensen KH, Rich D, Sjøstrøm G, Patil GG. Benefits of indoor plants on attention capacity in an office setting. Journal of Environmental Psychology. 2011;31(1):99-105. doi:10.1016/j.jenvp.2010.11.005

[95] Sempergreen. (2021, August 23). 5 reasons to introduce a green wall into your office. SemperGreenwall. https://sempergreenwall.com/news/5-reasons-to-introduce-a-green-wall-into-your-office/

Figure 3.1 : Green Walls in Solar Mosaic Company Office

Bloomberg Headquarters

Location: London,UK
Client: Bloomberg
Installation: -
Project Specialist: Foster+Partner's

Bloomberg's London office, designed by Foster + Partners, has gained recognition for its exceptional sustainable design and the BREEAM score of 98.5%. The facility's emphasis on environmental responsibility is evident in its innovative features such as grey water recycling and energy-efficient systems[96]. Within this environmentally conscious framework, it can be explored the potential impact of incorporating a living wall on the building's surroundings and occupants.

The living wall at Bloomberg's London headquarters plays a central role in the building's sustainability and biophilic design approach. This installation is envisioned to serve not only as an aesthetic element but also as a functional feature that contributes to the building's environmental principles and energy efficiency practices.

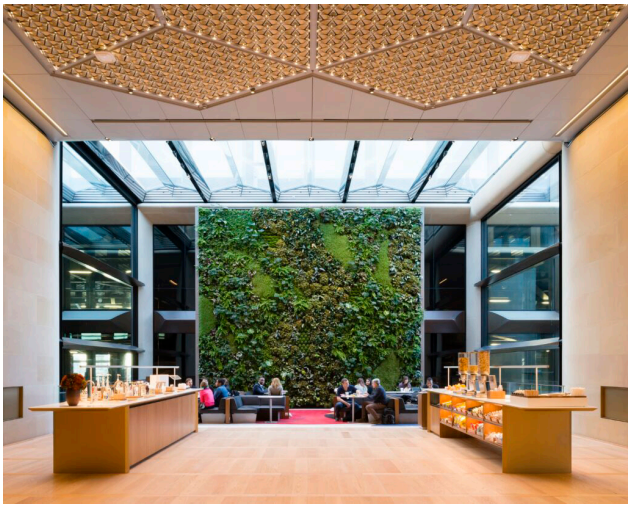

Figure 3.2 : Living Wall in Bloomberg's London Headquarters

The wall would function as a natural air filtration system, improving indoor air quality while utilizing collected grey water from the building's systems a demonstration of an integrated resource conservation strategy.

[96] Sisson P. World's most sustainable office space opens in London. Curbed. https://archive.curbed.com/2017/10/18/16496990/bloomberg-london-office-sustainable-design. Published October 18, 2017.

The pantry, with its high ceiling is an excellent location for meetings with colleagues and clients. Its ample natural light from the atrium above makes it an ideal location for our 'living wall'[97]. Its presence would introduce diversity within the modern pantry, promoting interaction among employees and encouraging them to connect with their surroundings. Serving as a natural partition, it would create areas of privacy and calmness providing employees with spaces for informal collaboration or introspection and thereby enhancing overall spatial dynamics within the workplace.

The living wall would serve as an enduring example of Bloomberg's commitment to environmental responsibility, playing a vital role in the building's life cycle by managing humidity and decreasing reliance on artificial climate control. The utilization of eco-friendly materials and vegetation would limit the wall's environmental footprint, adhering to the building's LEED criteria and strengthening its reputation as an exemplar of sustainable office architecture[98]. This integration reflects Foster + Partners' aim to incorporate nature into architectural design, promoting well-being and productivity among Bloomberg employees.

Figure 3.3 : Near shot Living Wall in Bloomberg's London office

Figure 3.4 : Bloomberg's London Headquarters pantry with green wall for meetings

[97] LP B. 5 Eco-Friendly features at Bloomberg's sustainable new European headquarters. Bloomberg L.P. Published December 9, 2022. https://www.bloomberg.com/company/stories/eco-friendly-features-bloombergs-new-european-headquarters/

[98] LP B. Why 36 of our offices are leading with LEED and BREEAM | Bloomberg LP. Bloomberg L.P. Published April 3, 2023. https://www.bloomberg.com/company/stories/offices-leading-leed/

KONE Corporation

Location: Espoo, Finland
Client: KONE
Installation: -
Project Specialist: NAAVA

In the last few years, there have been notable advancements in the design and arrangement of office spaces, with a growing emphasis on promoting employee welfare, sustainability, and maximizing space utilization. An exemplary instance of this progress can be seen in KONE Corporation's adoption of Naava green walls in their office setting.

Mobile vertical gardens, like the ones created by Naava, have become a groundbreaking component in contemporary office architecture. At KONE, these structures serve a dual purpose as they not only add aesthetic value but also act as flexible dividers that offer privacy and delineate separate areas within the open-concept office layout. The deliberate positioning of these green walls converts the vast office space into more secluded and personalized zones.

Figure 3.5 : Smart Wall systems by Naava for KONE Corporation's office.

This design decision reflects KONE's dedication to offering an invigorating, comfortable, and wellness-oriented workplace environment. Maintaining privacy and personal space in an open office design presents a challenge. At KONE, Naava green walls are utilized as natural dividers to address this issue[99].

[99] KONE. https://www.naava.io/en/references/kone

These living partitions create partially secluded spaces, providing employees with areas for concentrated work or private conversations. This spatial separation is established without the use of solid, non-transparent barriers, thus preserving the open and spacious atmosphere of the office.

In addition to serving as space dividers, the green walls make a noteworthy contribution to both the visual appeal of the office and the welfare of employees. The abundant green plants bring a natural element, improving the overall visual comfort of the area.Furthermore, these walls are known for their air-purifying properties which enhance indoor air quality, ultimately leading to increased productivity and energy levels among staff members. The Naava green walls are in line with KONE's commitment to sustainability, reflecting their emphasis on environmental responsibility and innovative solutions. The incorporation of remote monitoring technology for optimizing these walls is consistent with KONE's approach to smart, sustainable solutions. This shared design philosophy goes beyond visual appeal and supports KONE's wider goal of promoting sustainable urban development[100].

Figure 3.6: KONE Corporation's office environment with smart wall system by Naava

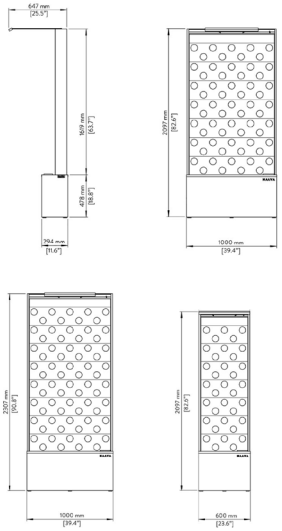

Figure 3.7 : Techical drawings of Smart wall system by Naava

[100] KONE. https://www.naava.io/en/references/kone

TELUS SKY TOWER

Location: Calgary,Canada
Client: ICON, Westbank
Installation: -
Project Specialist: (BIG) Bjarke Ingles Group, Heavy

The Telus Sky Tower in Canada is a prime demonstration of sustainable architecture, seamlessly blending natural elements into its design. This case study delves into the creative installation of an 8-story green wall in its atrium, showcasing a dedication to eco-friendly design and enhancing the building's spatial ambience for occupants.

Icon / Westbank enlisted the expertise of HEAVY to collaborate with BIG and Dialog in bringing to life their vision for a monolithic living wall planter system. The project required an attractive, cost-effective design that stayed true to the original concept. After rigorous 3D modeling, material sourcing, and site installation coordination, HEAVY suggested a unique approach: utilizing vacuum formed Avonite™ for the planters along with aluminum paneling for flat surfaces[101].

Figure 3.8: Green Wall in Telus Sky Tower detalied shot

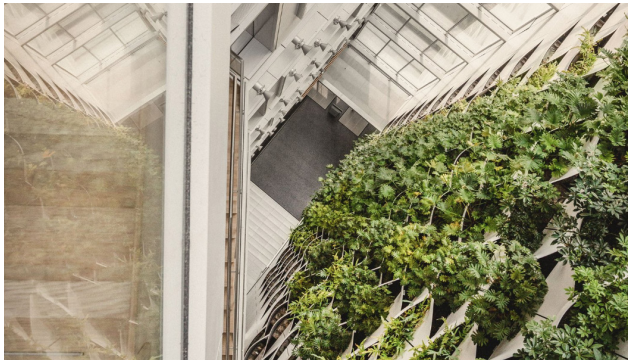

Figure 3.9: Green Wall in Telus Sky Tower shot from above

[101] Heavy—Placemaking, public art, & architectural features. Heavy.https://www.heavyexperience.com/telus-atrium-stairs-greenwall

This innovative solution achieved a modern aesthetic while providing an organic contrast within the environment. The living vertical garden in Telus Sky Tower is more than just a decorative feature; it plays a vital role as a structural component, altering the way space is perceived. As it ascends through the 11-storey atrium, it acts as an organic focal point that impacts how people move within the building. With its lush greenery, the wall provides a multi-dimensional encounter with nature that can be seen from different perspectives throughout the office areas, fostering a feeling of being linked to nature amidst the urban environment.

The architectural firm incorporated a stormwater management system in line with the tower's sustainable principles, utilizing rainwater to meet the structure's non-potable water requirements. This innovative system reduces reliance on the local water grid by 70%, demonstrating a progressive attitude towards resource utilization[102]. The living wall, nourished by this environmentally friendly system, serves as a physical representation of the tower's commitment to sustainability, improving the building's ecological impact and fostering a real link to nature for its inhabitants.

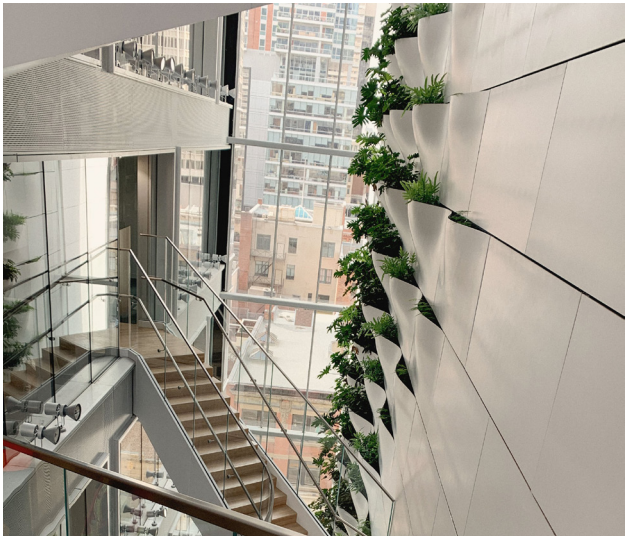

Figure 3.10: Green Wall in Telus Sky Tower from staircase view

Figure 3.11: Green Wall in Telus Sky Tower entrance

[102] Dreith B, Dreith B. BIG unveils Calgary skyscraper "composed to form a feminine silhouette." Dezeen. Published February 10, 2023. https://www.dezeen.com/2022/11/21/big-telus-sky-skyscraper-calgary/.

Green Walls in Educational Facilities

Psychological benefits of indoor plants on students in classrooms have also been reported[103]. Several research studies have demonstrated that replicating the outdoor experience indoors can yield similar positive effects. When incorporated in educational institutions, this approach has the potential to enhance academic performance and elevate the overall learning environment for both students and educators alike. Additionally, research suggests that simply being around plants can substantially improve memory retention by about 20 percent and boost test scores, this is attributed to plants' capacity to absorb, deflect, and dampen background noise such as outside traffic or playground activities, leading to a conducive learning atmosphere[104].

The benefits of green walls extend beyond enhancing academic performance; they also positively impact mental and physical well-being. Due to the intense academic expectations prevalent in schools, stress levels are often high. Indoor vertical gardens can naturally alleviate stress and anxiety. Incorporating greenery can lower carbon dioxide levels indoors by absorbing it from the air and producing oxygen instead, this can reduce symptoms such as headaches, dizziness, and fatigue, all of which can be detrimental to students' concentration abilities[105].

[103] Raanaas RK, Evensen KH, Rich D, Sjøstrøm G, Patil GG. Benefits of indoor plants on attention capacity in an office setting. Journal of Environmental Psychology. 2011;31(1):99-105. doi:10.1016/j.jenvp.2010.11.005

[104] Society FP. Green walls in schools: beyond health benefits and into curriculum. Medium. https://thefatplantsociety.medium.com/green-walls-in-schools-beyond-health-benefits-and-into-curriculum-3fdf69207204. Published December 6, 2021.

[105] Ackerman L. Living green walls in schools increase student performance and well being - Greenroofs.com. Greenroofs.com. Published January 13, 2020. http://www.greenroofs.com/2020/01/10/living-green-walls-in-schools-increase-student-performance-and-well-being/

Figure 3.12: Living wall at the University of Guelph Humber

Harvard University

Location: Cambridge, Massachusetts
Client: Harvard University
Installation: 2018
Project Specialist: MVVA, Michael Van Valkenburgh

At Harvard University's Smith Campus Center, a recent addition to the architectural landscape showcases sustainable innovation and social interaction. The installation comprises eight vertical gardens, known as living walls, which reach almost 20 feet in height. This transformation has turned the indoor area into a lively focal point for student activities. These living walls not only reimagine the university's classic ivy-covered exterior but also signify its dedication to establishing welcoming communal areas.

Figure 3.13: Green Walls in Smith Campus Center at Harvard University

Situated near Harvard Yard, the Smith Campus Center serves as a central hub for both visitors, student and members of the Harvard community. The incorporation of vertical gardens has changed the center from a basic walkway into an indoor area that showcases the attractiveness of the campus surroundings. In partnership with Hopkins Architects, MVVA, a landscape architecture firm, brought to life a vision stemming from Harvard's 2008 Common Spaces plan. This transformation aimed to create new areas for socializing and interaction within this historic setting[106]. As a result, the internal environment now emits liveliness from its external surroundings, establishing an appealing communal space that makes a memorable impact.

[106] Michael van Valkenburgh Associates Inc. Smith Campus Center at Harvard University. https://www.mvvainc.com/projects/smith-campus-center-at-harvard-university

Vertical gardens have a dual function, working to enhance both environmental comfort and air purity. These living walls actively absorb carbon dioxide and release oxygen, contributing directly to creating a healthier indoor atmosphere for students and visitors[107]. Furthermore, the use of rainwater gathered from the roof of the building for watering shows a firm dedication to sustainable practices in line with broader environmental awareness

These living vertical gardens incorporate sustainable technologies that go beyond simply purifying the air. By collecting rainwater and lowering energy needs through natural climate control, these green installations play a role in creating a more comfortable and energy-efficient building. The conversion of an originally oversized and uninspiring area into a vibrant, eco-friendly communal space illustrates how ecological approaches can be effectively combined with pre-existing structures. The redesign of the Smith Campus Center goes beyond just renovating; it represents a new way to reenvision educational settings, incorporating natural elements into a busy academic hub. This reflects the direction in which university spaces are headed ones that not only stimulate intellectually but also respond to environmental needs and foster social inclusiveness.

Figure 3.14: Green Walls from above shot in Smith Campus Center at Harvard University

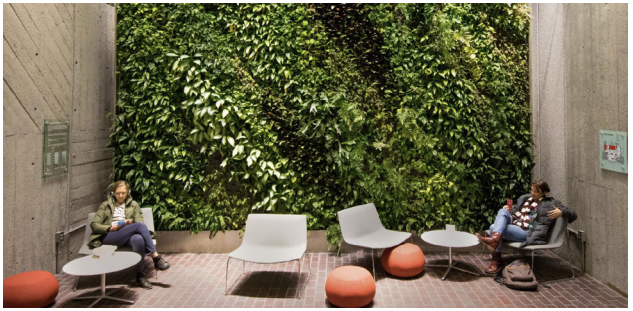

Figure 3.15: Green Wall in Smith Campus social space at Harvard University

Figure 3.16: Green Walls in Smith Campus cafeteria at Harvard University

[107] Michael van Valkenburgh Associates Inc. Smith Campus Center at Harvard University. https://www.mvvainc.com/projects/smith-campus-center-at-harvard-university

University of Ottawa

Location: Ottawa, Canada
Client: University of Ottawa
Installation: -
Project Specialist: Diamond Schmitt Architects

The Vanier Hall at the University of Ottawa represents more than just a building; it signifies a dedication to sustainability and academic distinction, evident through the installation of North America's largest living wall biofilter[108]. This innovative green wall system serves as a testament to the university's commitment to creating an inviting and healthy environment for its students. The six-story living wall changes the interior of the building into a serene oasis with captivating visual elements. Its abundant greenery provides a natural escape from the urban campus atmosphere, establishing areas where students can participate in introspective studying or collaborative learning. This corresponds with the broader educational goals of the University by potentially enhancing productivity and cognitive abilities among those who interact with it, ultimately enriching their educational experience.

Figure 3.17: Six-story living wall at the University of Ottawa

[108] Building Design & Construction. (2015, October 23). Six-story living wall improves building performance at University of Ottawa. Building Design + Construction. https://www.bdcnetwork.com/six-story-living-wall-improves-building-performance-university-ottawa

The living wall serves as more than a mere decorative aspect; it acts as an active biofilter, playing a functional role in the building's operation. Harnessing the potential of nature, this biofilter eliminates 80 – 85% of VOCs from indoor air, providing nearly the same quality as fresh outdoor air[109]. This natural filtration mechanism, supervised by microorganisms in the root media, establishes a healthier learning environment by supplying cleaner air that is crucial for sustaining cognitive sharpness and concentration. By reducing airborne pollutants, students can benefit from a lowered susceptibility to health issues commonly linked to poor indoor air quality, thereby bolstering their overall well-being and academic achievement.

In addition, the living wall contributes to creating a tranquil atmosphere with its control over dust levels, noise reduction properties, and its integrated water system producing soothing sounds. These collective features enhance individuals' sensory experience within the building,collectedly easing stress among students while promoting mental clarity,further supporting focused studying and productivity. Recent research carried out by Nedlaw Living Walls has not only shown the efficacy of the biofilter in eliminating indoor pollutants but also measured its financial benefits through energy conservation. Through reducing the requirement for conditioned outdoor air, the living wall biofilter decreases the building's energy consumption by as much as 30%, providing clean air at a lower cost compared to conventional systems[110]. This environmentally friendly strategy reflects the university's commitment to sustainable technology that enhances student well-being by establishing a more pleasant and economically efficient learning environment.

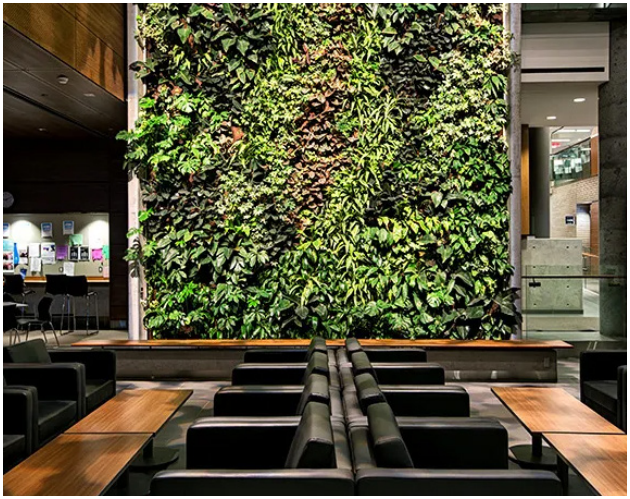

Figure 3.18: Living Wall at the University of Ottawa seating area view

[109] Building Design & Construction. (2015, October 23). Six-story living wall improves building performance at University of Ottawa. Building Design + Construction. https://www.bdcnetwork.com/six-story-living-wall-improves-building-performance-university-ottawa

[110] Building Design & Construction. (2015, October 23). Six-story living wall improves building performance at University of Ottawa. Building Design + Construction. https://www.bdcnetwork.com/six-story-living-wall-improves-building-performance-university-ottawa

University of Maryland

Location: USA
Client: University of Maryland
Installation: 2019
Project Specialist: Green Roofs

The University of Maryland demonstrates its dedication to sustainability and student welfare through the construction of the Building IV Biomedical Sciences & Engineering facility at Universities at Shady Grove. One significant environmentally-friendly measure is the introduction of an indoor living green wall by GSky Plant Systems, which supports the institution's biophilic design approach aimed at integrating educational spaces with natural elements.

The Green Wall is strategically positioned in the building atrium, creating a living ecosystem that seamlessly connects the interior lobby to the outdoor campus environment. Its gentle curves and diverse shades of green complement the building's architecture while acting as a focal point that improves spatial dynamics. It encourages students to engage with a tranquil setting, providing a welcomed contrast to the typically high-energy university atmosphere.

The positive effects of integrating plants into educational spaces are well-recognized by schools worldwide. Research at the University of Maryland has shown that being near a Green Wall can improve students' memory retention by up to 20%, thereby providing a natural way to enhance academic performance[111]. Additionally, having green walls in learning environments serves as a form of stress relief and helps create a more relaxing atmosphere, ultimately benefiting students' mental clarity and focus.

Apart from its cognitive benefits, the Versa Wall® also plays an important role in ensuring indoor environmental quality. This living wall acts as a natural air purifier, reducing carbon dioxide levels and airborne pollutants which contributes to better air quality.

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[111] The Universities at Shady Grove (USG) Biomedical Sciences & Engineering Living Wall - Greenroofs.com. Greenroofs.com. Published April 6, 2020. http://www.greenroofs.com/projects/the-universities-at-shady-grove-usg-biomedical-sciences-engineering-living-wall/

As a result, it can help reduce common health issues such as headaches, dizziness, and fatigue among students - conditions that often hinder learning and productivity.

The Green Wall system by GSky is engineered with simplicity and sustainability in mind. Its distinct tray design ensures convenient installation and upkeep, making the living wall a flexible feature within the building. The modular structure of the wall allows for artistic expression, accommodating other design elements, as well as seasonal changes at minimal expense. Furthermore, the personalized pot system supports plant health and longevity while enabling quick plant replacement and design modifications without significant disruption.

The vertical irrigation technology patented for the wall demonstrates the university's commitment to sustainability. With a gravity-based irrigation cycle that operates less than once a week, the Versa Wall® minimizes water wastage and oversaturation. This efficient system not only conserves water but also reduces maintenance costs compared to other green wall systems that may require more frequent watering[112].

Figure 3.19: Green Wall at the University of Marylands staircase

Figure 3.20: Green Wall from the above at the University of Maryland

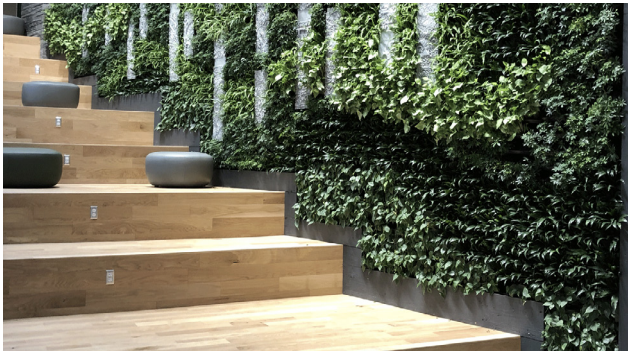

Figure 3.21: Green Wall detailed view at the University of Maryland

[112] The Universities at Shady Grove (USG) Biomedical Sciences & Engineering Living Wall - Greenroofs.com. Greenroofs.com. Published April 6, 2020. http://www.greenroofs.com/projects/the-universities-at-shady-grove-usg-biomedical-sciences-engineering-living-wall/

Green Walls in Community Spaces

Green walls can contribute to lowering the energy needs of buildings and offer ecological, climate-related, and community advantages including noise mitigation, enhancement of urban environments, elimination of pollutants, aesthetic improvements, alleviation of urban heat islands[113].

Incorporating green walls in community spaces can also promote a sense of community and civic pride. When these vibrant and visually appealing green spaces are integrated into the urban landscape, they can serve as focal points for social gatherings, events, and community activities. This not only enhances the physical surroundings but also fosters a greater sense of belonging and connection among residents.

Overall, the incorporation of green walls in community spaces can offer a wide range of benefits, including environmental, social, and psychological advantages that contribute to the well-being of individuals and the community as a whole.

[113] Susca T, Zanghirella F, Colasuonno L, Del Fatto V. Effect of green wall installation on urban heat island and building energy use: A climate-informed systematic literature review. Renewable & Sustainable Energy Reviews. 2022;159:112100. doi:10.1016/j.rser.2022.112100

Figure 3.22: Jewel Changi Airport in Singapore

Kempegowda International Airport Bengaluru

Location: Bengaluru, Karnataka, India
Client: Kempegowda International Airport
Installation: 2023
Project Specialist: Abu Jani and Sandeep Khosla, SOM

Bengaluru's Kempegowda International Airport, located in one of India's most prominent and rapidly expanding urban centers, has adopted an innovative strategy for its latest terminal, Terminal 2. Embracing the city's renowned title as the "garden city," this initiative - developed through a partnership between SOM, Grant Associates, and designers Abu Jani and Sandeep Khosla - transforms the travel environment by incorporating natural features into its design to establish itself as a "terminal within a garden."

Figure 3.23: Belgaru's Kempegowda International Airport Terminal 2 green walls passage

Terminal 2's design represents a major shift from conventional airport architecture, highlighting the cultural and environmental significance of Bengaluru. Spanning across 255,000 square meters, this terminal serves as an important civic entrance that harmoniously integrates airport infrastructure with verdant natural surroundings[114]. Upon entering the transit hub, passengers are surrounded by a series of garden-inspired areas featuring green walls, suspended gardens, and forest belt. The passage through the terminal resembles a stroll in a garden pavilion, complete with a ceiling made of engineered bamboo that filters light to produce a peaceful atmosphere.

[114] Skidmore, Owings & Merrill (SOM). Kempegowda International Airport Bengaluru - Terminal 2 – SOM. SOM. Published February 1, 2024. https://www.som.com/projects/kempegowda-international-airport-bengaluru-terminal-2/

Terminal 2 serves as an example of environmentally conscious airport architecture, being the biggest airport structure globally to achieve precertification as a LEED Platinum building. Its design philosophy prioritizes sustainability and well-being, relying completely on renewable energy through initiatives such as solar sharing and advanced building systems[115]. The incorporation of rainwater harvesting systems for irrigation and natural cooling waterfalls in the retail area reflects a comprehensive commitment to environmental stewardship.

Terminal 2 goes beyond being just a place for travelers to pass through; it offers a serene environment and an opportunity to connect with nature during their journey. By incorporating gardens and natural features, the terminal not only enhances its visual appeal but also promotes the well-being of passengers by helping to alleviate the stress commonly experienced during air travel.

Figure 3.24: Belgaru's Kempegowda International Airport Terminal 2 from above

Figure 3.25: Belgaru's Kempegowda International Airport Terminal 2 green walls passage detailed view

Figure 3.26: Green Wall near to departue information table in Belgaru's Kempegowda International Airport Terminal 2

[115] Skidmore, Owings & Merrill (SOM). Kempegowda International Airport Bengaluru - Terminal 2 – SOM. SOM. Published February 1, 2024. https://www.som.com/projects/kempegowda-international-airport-bengaluru-terminal-2/

California Academy of Sciences

Location: San Francisco, CA
Client: California Academy of Science
Installation: 2011
Project Specialist: Habitat Horticulture, David Brenner, Renzo Piano

The California Academy of Sciences is celebrated as one of the biggest natural history museums globally, with a collection of 26 million specimens[116]. Located in San Francisco, its modern architecture and commitment to environmental conservation make it an exceptional example. Renzo Piano's design integrates light and nature, forming a vibrant environment that includes Habitat Horticulture's living wall in the museum's main hall. The strategically placed living wall is designed to captivate visitors as they enter, acting as a vibrant display that reflects the museum's commitment to the natural world.

Figure 3.27: Living wall at the California Academy of Sciences

Figure 3.28: Detalied view Living wall at the California Academy of Sciences

[116] Habitat Horticulture | California Academy of Sciences Living Wall. https://habitathorticulture.com/projects/california-academy-of-sciences

It serves as a focal point that not only complements the wide range of exhibits in the museum but also enriches the overall spatial experience. Renzo Piano implemented choices related to building materials and integrated environmentally-friendly elements such as natural light, ventilation, water conservation, rainwater recycling, and energy production. These considerations played a crucial role in securing the museum's LEED platinum certification[117].

The living wall exemplifies this philosophy and represents the Academy's dedication to environmental balance. It functions as an educational tool for visitors, showcasing the real-world implementation of sustainable design and biodiversity. It promotes a greater understanding of efforts to conserve natural resources and cultivates awareness about impact on ecological systems.

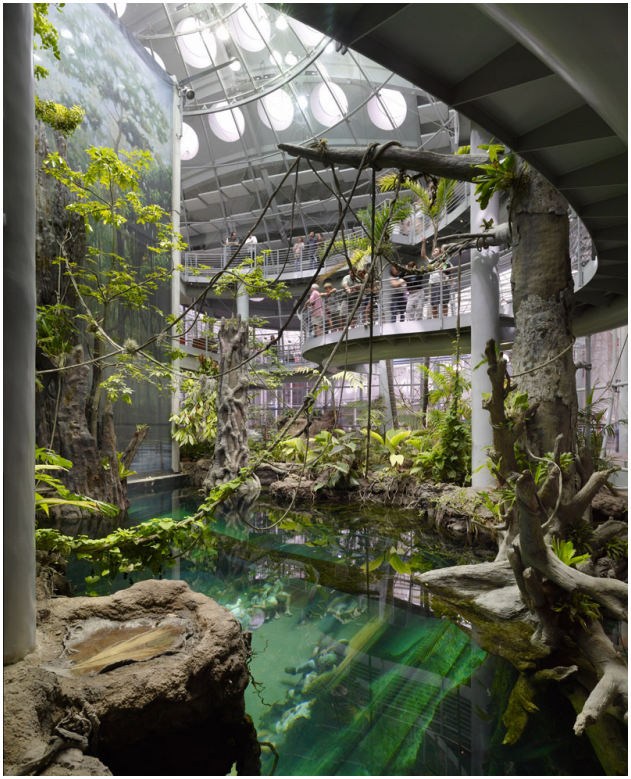

Figure 3.29: Inside rainforest dome, with flooded forest below, California Academy of Sciences

[117] Fracalossi I. California Academy of Sciences / Renzo Piano Building Workshop + Stantec Architecture. ArchDaily. Published December 31, 2022. https://www.archdaily.com/6810/california-academy-of-sciences-renzo-piano

Re:Mind Studio

Location: London, UK
Client: Re:Mind Studio
Installation: 2018
Project Specialist: Oliver Heath Design, Biotecture

Re:Mind Studio in London has transformed the idea of an urban sanctuary with its inventive and nature-inspired layout. Serving as a haven for meditation, healing, and breathwork, the studio showcases how biophilic design can revamp a wellness area to foster tranquility and relaxation within a lively city setting.

Re:Mind's spatial design features a vibrant floor-to-ceiling green wall by Biotecture, which serves as more than just a background. It functions as an integral, living element of the studio, elevating the meditative ambiance. Positioned strategically as one of the central focal points, this design decision demonstrates a profound reverence for nature and sustainability while embracing biophilic principles to establish a strong bond between humans and the natural world.

The green wall is a key factor in the studio's emphasis on health and well-being. It helps to eliminate toxins and lower CO2 levels, playing a crucial role in creating a healthy indoor environment. These natural elements are known for their ability to lower heart rates and blood pressure, enhancing the overall therapeutic effect of the studio. Furthermore, using low VOC materials and a HEPA filter air filtration system demonstrates commitment to ensuring top-notch air quality, which is particularly important in an urban setting[118].

[118] Re:Mind Studio, Oliver Heath. Oliver Heath. https://www.oliverheath.com/our-projects/remind/

The arrangement of the plants, inspired by a subtropical stream's ripple pattern, consists of indoor-friendly plant varieties. This green wall serves as an efficient solution for maximizing space in urban settings and plays a key role in creating a serene atmosphere within the studio. The selection and positioning of the plants have been thoughtfully planned to ensure their flourishing in the indoor climate maintained at 17°C or higher[119].

The living wall at Re:mind studio has been well received by students and educators, representing a successful incorporation of nature into an urban wellness environment. The studio has fulfilled its goal of establishing a space where individuals can immediately feel an improvement compared to being outside, providing a retreat to nature within the city center.

Figure 3.30: Green wall by Biotecture in the meditation room at Re:mind studio

Figure 3.31: Detailed view of the green wall by Biotecture in the meditation room at Re:mind studio

[119] Victoria Living Wall at Re:mind Studio ceates a tranquil zone - Biotecture. Published November 20, 2019. https://www.biotecture.uk.com/portfolio/remind-studio-victoria-living-wall/

Singapore Changi Airport

Location: Singapore
Client: Changi Airport
Installation: 2023
Project Specialist: Moshe Safdie Architects, Tierra Design

Jewel Changi Airport, designed by Moshe Safdie and Safdie Architects, represents a pinnacle of innovation in Singapore's international travel hub. Its remarkable architectural elements, such as the indoor waterfall and abundant greenery, showcase a dedication to sustainable design. This commitment is also evident in the monumental living wall at Changi Airport Terminal 3, which serves both aesthetic and environmental purposes with its design by Tierra Design.

The green wall in Terminal 3 serves as a fundamental element of the terminal's design, representing a "City in a Garden" and a communal space within the airport. Spanning over 4,100m2, it is one of the world's largest indoor green walls and includes 10,000 plants from 25 different species[120].

Figure 3.32: Living walls at Changi Airport Terminal 3

Figure 3.33: Living walls at Changi Airport Terminal 3 view from below

[120] Tierra Design. Singapore Changi Airport Terminal 3 - Tierra Design. Tierra Design - Highly Motivated, Multidisciplinary and Multicultural Architectural and Landscape Design Practice. Published July 22, 2021. https://tierradesign.com.sg/projects/singapore-changi-airport-terminal-3/

This vertical garden functions as a dynamic living artwork that enriches the airport environment by introducing natural serenity into its usually busy atmosphere.

The green walls in Terminal 3 creates a peaceful sanctuary, providing a revitalizing and inviting environment for travelers. It plays a role in improving air quality by utilizing the diverse range of plants to filter the air naturally and reduce carbon emissions within the area[121]. This display of greenery represents Changi Airport's commitment to sustainability, demonstrating how biophilic design can be incorporated into contemporary architecture to promote both well-being and environmental wellness. Skilled technicians perform regular maintenance to preserve the vitality of the wall within the terminal's ecosystem. This living feature reflects Changi Airport's dedication to establishing enduring, eco-friendly spaces with aesthetic value.

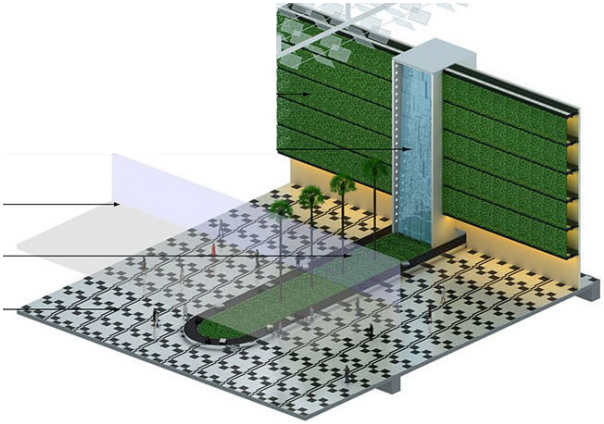

Figure 3.34: Living walls technical drawing plan at Changi Airport Terminal 3

Figure 3.35: Living walls at baggage claim points in Changi Airport Terminal 3

[121] Changi takes Big Steps to go green | Changi Airport Group. (n.d.). https://www.changiairport.com/corporate/media-centre/changijourneys/the-airport-never-sleeps/changi-takes-big-steps-to-go-green.html

Green Walls in Residential Interiors

Green walls in homes blend aesthetic appeal with functionality, making a distinctive style statement that enhances the atmosphere and value of residential spaces. Beyond their visual impact, they also play a vital role in purifying indoor air quality, contributing to a tranquil and rejuvenating home environment. The presence of green walls improves the well-being of residents, creating a serene haven and enhancing the overall living experience. Moreover, these environmentally friendly installations resonate with eco-conscious values while potentially boosting property appeal and marketability[122]. Therefore, green walls serve not only as decorative features but also as strategic investments in residential design that elevate both the physical space and inhabitants' quality of life.

[122] Green Walls for Homes | Living Walls for Homes | Living Walls UK. Published April 26, 2021. https://www.livingwallsuk.co.uk/services/green-walls-for-homes/

Figure 3.36: Living wall, designed by David Brenner of Habitat Horticulture, in Roberta Riga's San Francisco Bay Area home

Cobble Hill Carriage House

Location: NY, USA
Client: Private
Installation: -
Project Specialist: Ingui architecture, Ellen Hamilton Interior Design

A historic carriage house in Cobble Hill has been renovated into a striking residential space that seamlessly integrates contemporary design with the timeless allure of its environment. The focal point of this renovation is an 18-foot tall living wall which extends over two levels, bringing a natural element into the residence and creating an immersive spatial ambiance[123].

The living wall, which incorporates a vertical garden within the residence, embodies biophilic design principles by highlighting humans' innate connection to nature. Extending over two levels, this green wall is a dynamic living artwork that grows and changes over time while also enhancing the residents' well-being.

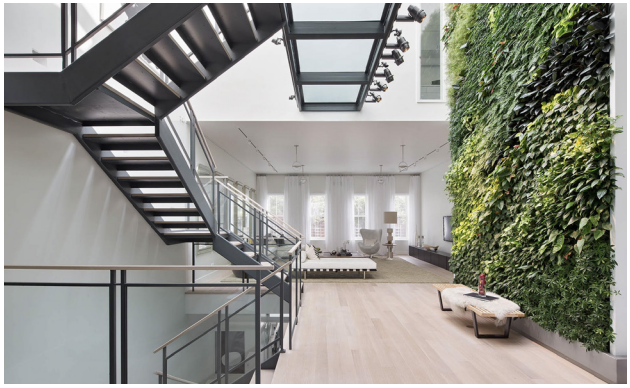

Figure 3.37: Living wall in Cobble Hill Carriage House by Inguiarchitecture

Figure 3.38: Living wall from staircase view in Cobble Hill Carriage House

[123] Cobble Hill Carriage House. Ingui Architecture. Published August 12, 2021. https://www.inguiarchitecture.com/projects/degraw-street-cobble-hill

The living wall improves indoor air quality, regulates humidity levels within the home, and provides a calming visual backdrop for daily enjoyment by inhabitants.

The renovation was meticulously planned to ensure that the light not only enhances the home's openness but also sustains the living wall. The glass walkway on the third floor providing a pathway that connects spaces without obstructing light or views of the green wall.

The living wall provides residents with more than just a visually appealing green feature; it also fosters a feeling of calm and balance. In urban settings, where concrete is prevalent, the inclusion of a two-story vertical garden within the home offers an opulent escape a daily link to the natural environment that can elevate spirits, alleviate tension, and enhance mental acuity.

The Cobble Hill Carriage House serves as evidence of eco-friendly modern living. This integration of sustainable methods reflects a commitment to an environmentally conscious lifestyle while maintaining high standards in luxury and design[124].

Figure 3.39: Living wall in Cobble Hill Carriage House with a view of glass ceiling https://www.inguiarchitecture.com/projects/degraw-street-cobble-hill

[124] Cobble Hill Carriage House. Ingui Architecture. Published August 12, 2021. https://www.inguiarchitecture.com/projects/degraw-street-cobble-hill

GST Private House

Location: Turin, Italy
Client: Private
Installation: -
Project Specialist: Sundar Italia

Sundar Italia has created a vertical garden in a Turin penthouse, integrating the natural surroundings into the living space. This green wall comprises approximately 600 plants spread across nearly 9 square meters and features 18 different species.

The living wall functions as an attractive feature, adding vibrancy and a feeling of inviting comfort to the space. It serves a practical purpose by oxygenating and cleansing the air, promoting the general health and wellness of those in the area. Additionally, it has a natural ability to absorb sound, fostering a tranquil and calm environment in an urban setting.

Sundar Italia's method for creating a living wall adapts the technique developed by French botanist Patrick Blanc. It involves cultivating plants on FOREX panels with layers of felt, using hydroponic techniques[125].

Figure 3.40: Living wall created by Sundar Italia in a Turin Penthouse

Figure 3.41: Living wall created by Sundar Italia in a Turin Penthouse detailed view

[125] Scalco C. Il verde verticale di Sundar Italia per un attico torinese | Area. Area. Published September 16, 2020. https://www.area-arch.it/il-verde-verticale-di-sundar-italia-per-un-attico-torinese/

A modular structure is used to support these panels, promoting proper ventilation and the growth of the green wall. The selection of plants is customized through collaboration between the client and a botanical specialist to ensure optimal adaptation to the home's environmental conditions and desired visual appeal.

The vertical garden features an automated fertilization control system and Wi-Fi connectivity to the Garden Monitoring Network, providing real-time notifications of any irregularities that could affect plant health. Sundar Italia offers dependable after-sales assistance to preserve the durability and aesthetics of the green wall for a prolonged duration[126].

In this contemporary penthouse, the green wall serves as a central feature that complements the aesthetics of the interior design, creating a feeling of increased coziness and harmony. The wall's active character ensures ongoing transformation, presenting inhabitants with a constantly shifting array of plants to explore and appreciate daily.

Figure 3.42: Living wall with a small window view created by Sundar Italia in a Turin Penthouse

Figure 3.43: Living wall created by Sundar Italia in a Turin Penthouse living room

[126] Scalco C. Il verde verticale di Sundar Italia per un attico torinese | Area. Area. Published September 16, 2020. https://www.area-arch.it/il-verde-verticale-di-sundar-italia-per-un-attico-torinese/

The House of Elements

Location: London, UK
Client: Private
Installation: 2023
Project Specialist: Biotecture, Neil Dusheiko

The remodelling of a Peckham residence by Biotecture and Neil Dusheiko Architects demonstrates the potential of integrating living biotic elements within residential structures. The living wall was designed to bring vitality and create a tranquil sanctuary aligned with the client's cultural heritage. Central to the transformation was the creation of a double-height space that opened up visual and atmospheric aspects, contrasting with the previous darkened interiors. A bespoke living wall extends vertically over two floors, serving as a backdrop to the extended kitchen. Its verticality introduces new spatial dimensions, enabling visibility and naturalistic immersion across different sections of the home.The skylight allows sunlight to reach the living wall, helping different plant species thrive[127].

Figure 3.44: Living wall created by Biotecture at the House of Elements in London

[127] The house of elements; internal living wall - biotecture. Biotecture. Published January 23, 2024. https://www.biotecture.uk.com/portfolio/the-house-of-elements-internal-living-wall/

The plants were carefully chosen to suit their light preferences, improving both biological health and visual appeal of the green wall. Biotecture rigorously designed and managed the green wall to ensure it integrated well into the architectural scheme and built environment. Biotecture's BioPanel system, based on hydroculture techniques, was implemented in two phases to integrate the wall and ensure its structural and botanical maintenance. The system includes automated fertigation and Wi-Fi-enabled monitoring for meticulous oversight of the wall's vegetative components, ensuring continuity in aesthetic appeal and environmental benefits[128].

The living wall in this Peckham residence goes beyond just visually enhancing the space. It embodies a holistic approach to residential design that focuses on environmental harmony and well-being. By creating a direct link to nature within the home, the living wall reflects the client's desire for an environment filled with liveliness and calmness. This highlights the increasing acknowledgment of biophilic design as an important aspect of modern architectural practice.

Figure 3.45: Detailed view of the living wall created by Biotecture at House of Elements in London

Figure 3.46: Living wall view from the bathroom at the House of Elements in London

[128] The house of elements; internal living wall - biotecture. Biotecture. Published January 23, 2024. https://www.biotecture.uk.com/portfolio/the-house-of-elements-internal-living-wall/

Home KubusEiland

Location: Utrecht, The Netherlands
Client: Private
Installation: -
Project Specialist: SemperGreenWall

The idea of integrating natural elements into indoor spaces is demonstrated in the interior design of the KubusEiland residence in Utrecht, where a SemperGreenwall Indoor has been utilized[129]. This analysis highlights how the green wall serves as both a division within the space and an attractive enhancement to the home's contemporary style.

The green wall within the KubusEiland residence has a twofold purpose. It serves as a natural divider that subtly separates the dining area from the living space without the presence of a solid barrier. This application of vertical greenery as a division element showcases creative spatial planning, enabling an open-plan arrangement while preserving separate functional areas within the house.

Figure 3.47: Green wall by Sempergreenwall at home KubusEiland at Ultrecht

[129] Green walls for home on the KubusEiland in Utrecht. SemperGreenwall. Published August 24, 2021. https://sempergreenwall.com/projects/sempergreenwall-home-kubuseiland-utrecht/

The green wall seamlessly integrates with the modern design of the house, enhancing its contemporary look by incorporating natural elements. Careful consideration was given to choosing plants that would complement the clean and simple style of the home, resulting in a striking contrast between man-made structures and organic features.

The SemperGreenwall Indoor creates a peaceful environment, improving the mental health of the residents. Its soothing effects offset the typically sterile modern layout, bringing an essence of liveliness and calmness to the area.

Figure 3.48: Green wall by Sempergreenwall in the living room at home KubusEiland in Ultrecht

IMPLICATIONS FOR FUTURE

Integration to large indoor spaces

The advancement of contemporary architecture has led to a significant shift towards design practices that prioritize sustainability and human well-being. As buildings become larger and more intricate, there is a growing need to balance designs that are focused on people with those that are environmentally responsible. Green walls exemplify the human desire for nature within modern interiors, which often lack natural elements. These living installations play an essential role in creating a sense of energy and calmness within constructed spaces. Incorporating green walls into interior settings provides a holistic experience that can reduce the stress of city life and cultivate a serene atmosphere.

In large indoor areas such as atriums, lobbies, and open-plan offices, green walls offer an adaptable solution by fitting various spatial dimensions while introducing nature indoors. These vertical gardens have the capacity to convert expansive walls into tranquil areas, making them fundamental aspects of interior architecture that enhance overall space ambiance.

Enhancing Well-being

Following the global pandemic, people are spending more time indoors, which has worsened mental health problems such as anxiety and depression[130]. Therefore, innovative interior design approaches are required to promote psychological well-being. Green walls are an excellent example of biophilic design, where nature and habitat intersect, and can serve as a therapeutic element within the built environment. Recent studies have highlighted the healing benefits of connecting with nature, environments incorporating natural elements can significantly reduce negative emotions such as anxiety, fatigue, and depression, and is effective in relieving emotional stress and enhance positive ones[131].

The inclusion of green walls in indoor spaces may reduce stress by lowering oxyhemoglobin concentration in the prefrontal cortex and promoting relaxation through activation of parasympathetic responses[132].

Green walls can be used as a psychological intervention in various environments, including homes, workplaces to promote mental health. They have the potential to induce positive emotions and reduce anxiety, making them active contributors to emotional well-being.

[130] World Health Organization: WHO. COVID-19 pandemic triggers 25% increase in prevalence of anxiety and depression worldwide. World Health Organization. https://www.who.int/news/item/02-03-2022-covid-19-pandemic-triggers-25-increase-in-prevalence-of-anxiety-and-depression-worldwide. Published March 2, 2022.

[131] Youn C, Chung L, Kang M, Kim S, Choi H, Lee J. Effects of green walls on prefrontal cerebral hemodynamics in hospital workers. Journal of People, Plants, and Environment. 2022;25(6):717-728. doi:10.11628/ksppe.2022.25.6.717

[132] Youn C, Chung L, Kang M, Kim S, Choi H, Lee J. Effects of green walls on prefrontal cerebral hemodynamics in hospital workers. Journal of People, Plants, and Environment. 2022;25(6):717-728. doi:10.11628/ksppe.2022.25.6.717

Accessibility and Inclusion

As sustainable interior design evolves, it is crucial to consider the accessibility and inclusion of green walls. These benefits should not be limited to highend commercial or residential spaces. Instead, they should be available to a wider audience, allowing everyone to enjoy the therapeutic and environmental advantages of green walls.

Integrating green walls in various settings, such as schools, hospitals, community centers, and affordable housing, could significantly contribute to public health and well-being. Access to natural elements should be recognized as a basic right, not a privilege, reflecting a commitment to health equity and environmental justice.

Making green walls an integral part of every interior space ensures that the benefits they provide are shared by all.To achieve this, it is necessary to employ certain strategies. These may include developing cost-effective green wall systems that are easy to install and maintain, making them more accessible for budget-conscious projects, and encouraging policies that incentivize the incorporation of biophilic design elements in public and private buildings, particularly in underserved communities.

IMPLICATIONS FOR DESIGN

Integration into Design Processes

Architects and interior designers should prioritize green walls as essential elements from the beginning, taking into account their structural, aesthetic, and environmental impacts during the initial design stage. This proactive approach allows designers to effectively address factors like natural light, humidity levels, and air circulation to ensure that the green wall enhances the space. Moreover, integrating green walls early on enables a smooth incorporation into the building's water and nutrient delivery systems, establishing them as an integral part of the building's ecosystem.

User-Centric Research

To gain a comprehensive understanding of the influence of green walls on individuals, further research needs to explore how these living components impact daily routines, emotional well-being, and overall health. This involves carrying out long-term studies that observe how engaging with or simply being around green walls can affect emotions, efficiency, and levels of stress among those in the building. This research should aim to collect both qualitative and quantitative data to provide a thorough overview of user experiences. It may ultimately aid in customizing green wall features based on specific user requirements and choices.

Sustainability Assessment

Assessing the ecological effect of green walls necessitates a prolonged outlook, encompassing not just their immediate advantages like air filtration and temperature control, but also their broader role in minimizing a building's environmental impact. Extended research should evaluate variables including power usage, water consumption, and the ability of green walls to store carbon. This extensive method will offer a valuable understanding of the long-term advantages of green walls, guiding optimal approaches for their planning, care, and inclusion in eco-friendly building accreditations.

The increasing awareness of sustainability is expected to lead to a rise in the popularity of living walls. Architects and designers are acknowledging their significant potential in converting buildings into energy-efficient and environmentally-friendly structures.

With advancements in technology, including efficient irrigation systems and automated maintenance, living walls are becoming more practical and attainable for a wider variety of building types and locations. In essence, living walls present a promising solution to some environmental and health challenges encountered by modern cities. Their capacity to enhance air quality, conserve energy, reduce noise pollution, promote biodiversity, and improve well-being makes them valuable enhancements to any building. By utilizing the benefits of greenery, these installations are revolutionizing the way we design and interact with buildings; ultimately contributing towards a more sustainable future[133].

[133] Energy EC. Green Walls reinventing energy efficiency in architectural design. Utilities One. https://utilitiesone.com/green-walls-reinventing-energy-efficiency-in-architectural-design. Published December 1, 2023.

Technological Innovation

As technology advances, the design and integration of green walls should also progress. Continual exploration and advancement in this area are essential for identifying new materials, watering techniques, and types of plants that can amplify the health and eco-friendly advantages of green walls. Developments in sensor technology and automated systems can additionally improve the environmental conditions required for plant growth, increasing the adaptability and maintenance convenience of green walls. It is important to consistently evaluate these technological improvements to ensure they align with evolving wellness needs across various environments.

By accepting these suggestions, stakeholders in the fields of architecture and interior design can progress towards incorporating green walls in a way that emphasizes human health and environmental sustainability. The objective is to convert indoor areas into healthier, livelier environments that encourage a stronger bond between occupants and the natural world. Ultimately, thoughtfully integrating green walls into interior design offers the potential to enhance individuals' quality of life and make a positive contribution to society's overall well-being.

CONCLUSION

Based on the extensive research and analysis conducted throughout this study, this thesis explores the multifaceted characteristics of green wall systems and their challenges in contemporary indoor environments. It is clear that green walls offer significant advantages for improving interiors, such as enhancing indoor air quality, well-being, mental physical health, aesthetics. From their historical origins to modern interpretations, these living installations bridging the gap between built environments and the natural world bring profound ecological, psychological and spatial implications.

However, it is crucial to recognize the importance of plant selection and maintenance in ensuring the longevity and effectiveness of green wall systems. While these systems offer numerous benefits, maintenance is essential for optimal performance and sustainability over time.

To maximize the ecological and economic viability of green wall installations, proposed design solutions serve as recommendations for designers. These solutions involve using life cycle assessment, integrating AI and smart technology for maintenance optimization, selecting appropriate plant species, and utilizing sustainable materials in system structures. With these recommendations, designers emphasize the points to be considered when integrating systems into the interior space.

A comprehensive understanding of existing green wall systems available in the market has been achieved through the examination of 11 green wall types, with real-world examples provided to illustrate their applications. Users can select the most suitable system based on their specific requirements and constraints after examining their advantages and disadvantages.

Additionally, a categorization effort has classified green wall systems based on their functionalities within interior spaces. Each typology has been evaluated against interior well-being requirements, highlighting the impact of these systems on enhancing indoor environments. The analyses show that each green wall system has a unique influence on interior well-being requirements, emphasizing their importance in fostering healthier and more sustainable indoor environments.

The study is expended by case studies in different environments, providing insights into green wall systems in various spaces and understanding their impact in improving indoor living and working conditions.

Several implications have been proposed for designers and stakeholders looking towards the future. These implications are: integrating green wall systems into larger indoor spaces, enhancing well-being, promoting accessibility and inclusion, integrating these systems into design processes, conducting user-centric research, performing sustainability assessments, and fostering technological innovation.

The integration of green wall systems represents a relationship between human well-being and environmental sustainability. As we face the challenges of rapid urbanization and environmental degradation, green walls offer a solution that harmonizes the built environment with the natural world. By adopting sustainable design principles and prioritizing human-centered approaches, interiors can be created that inspire and rehabilitate while contributing to a more resilient and harmonious future for generations to come.

Key findings highlight the indispensable role of green walls in fulfilling humanity's need to connect with nature, while at the same time alleviating stress-related psychological disorders and increasing productivity in work and educational environments. It is concluded that green wall installations are dynamic solutions that promote wellbeing in interior spaces. There is an need for future interior designs to integrate green wall systems, recognizing their potential to reduce the harmful effects of indoor air quality and improve overall wellbeing for people.

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Figure 3.20: Green Wall from the above at the University of Maryland

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Figure 3.21: Green Wall detailed view at the University of Maryland

http://www.greenroofs.com/projects/the-universities-at-shady-grove-usg-biomedical-sciences-engineering-living-wall/

Figure 3.22: : Jewel Changi Airport in Singapore

https://tcbgroup.com/history-of-changi-airport/

Figure 3.23: Belgaru's Kempegowda International Airport Terminal 2 green walls passage

https://www.som.com/projects/kempegowda-international-airport-bengaluru-terminal-2/

Figure 3.24: Belgaru's Kempegowda International Airport Terminal 2 from above

https://www.som.com/projects/kempegowda-international-airport-bengaluru-terminal-2/

Figure 3.25: Belgaru's Kempegowda International Airport Terminal 2 green walls passage detailed view

https://www.som.com/projects/kempegowda-international-airport-bengaluru-terminal-2/

Figure 3.26: Green Wall near to departue information table in Belgaru's Kempegowda International Airport Terminal 2

https://www.som.com/projects/kempegowda-international-airport-bengaluru-terminal-2/

Figure 3.27: Living wall at the California Academy of Sciences

https://habitathorticulture.com/projects/california-academy-of-sciences

Figure 3.28: Detalied view Living wall at the California Academy of Sciences

https://habitathorticulture.com/projects/california-academy-of-sciences

Figure 3.29: Inside rainforest dome, with flooded forest below, California Academy of Sciences

https://www.gardenvisit.com/gardens/california_academy_of_sciences

Figure 3.30: Green wall by Biotecture in the meditation room at Re:mind studio

https://www.remindstudio.com

Figure 3.31: Detailed view of the green wall by Biotecture in the meditation room at Re:mind studio

https://www.oliverheath.com/our-projects/remind/

Figure 3.32: Living walls at Changi Airport Terminal 3

https://tierradesign.com.sg/projects/singapore-changi-airport-terminal-3/

Figure 3.33: Living walls at Changi Airport Terminal 3 view from below

https://tierradesign.com.sg/projects/singapore-changi-airport-terminal-3/

Figure 3.34: Living walls technical drawing plan at Changi Airport Terminal 3

https://tierradesign.com.sg/projects/singapore-changi-airport-terminal-3/

Figure 3.35: Living walls at baggage claim points in Changi Airport Terminal 3

https://tierradesign.com.sg/projects/singapore-changi-airport-terminal-3/

Figure 3.36: Living wall, designed by David Brenner of Habitat Horticulture, in Roberta Riga's San Francisco Bay Area home

https://www.wsj.com/articles/planted-walls-take-root-in-homes-1527172460

Figure 3.37: Living wall in Cobble Hill Carriage House by Inguiarchitecture

https://www.inguiarchitecture.com/projects/degraw-street-cobble-hill

Figure 3.38: Living wall from staircase view in Cobble Hill Carriage House

https://www.inguiarchitecture.com/projects/degraw-street-cobble-hill

Figure 3.40: Living wall created by Sundar Italia in a Turin Penthouse

https://en.sundaritalia.com/progetti/giardino-verticale-interno/gst-torino

Figure 3.41: Living wall created by Sundar Italia in a Turin Penthouse detailed view

https://en.sundaritalia.com/progetti/giardino-verticale-interno/gst-torino

Figure 3.42: Living wall with a small window view created by Sundar Italia in a Turin Penthouse

https://en.sundaritalia.com/progetti/giardino-verticale-interno/gst-torino

Figure 3.43: Living wall created by Sundar Italia in a Turin Penthouse living room

https://en.sundaritalia.com/progetti/giardino-verticale-interno/gst-torino

Figure 3.44: Living wall created by Biotecture at the House of Elements in London

https://www.biotecture.uk.com/portfolio/the-house-of-elements-internal-living-wall/

Figure 3.45: Detailed view of the living wall created by Biotecture at House of Elements in London

https://www.biotecture.uk.com/portfolio/the-house-of-elements-internal-living-wall/

Figure 3.46: Living wall view from the bathroom at the House of Elements in London

https://www.biotecture.uk.com/portfolio/the-house-of-elements-internal-living-wall/

Figure 3.47: Green wall by Sempergreenwall at home KubusEiland at Ultrecht

https://sempergreenwall.com/projects/sempergreenwall-home-kubuseiland-utrecht/

Figure 3.48: Green wall by Sempergreenwall in the living room at home KubusEiland in Ultrecht

https://sempergreenwall.com/projects/sempergreenwall-home-kubuseiland-utrecht/